MINING AND MILLING METHODS AND COSTS, OZARK ORE CO. IRON MOUNTAIN IRON-ORE MINE, ST. FRANCOIS COUNTY, MO.

BY ROBERT F. PETTIT, JR., WILLIS A. CALHOUN, AND BURTON M. REYNOLDS

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Robert F. Pettit, Jr.,[1] Willis A. Calhoun,[2] and Burton M. Reynolds[1]

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INTRODUCTION

This paper on methods and costs of mining and milling iron ore at the Iron Mountain mine of Ozark Ore Co., St. Francois County, Mo., is one of a series of Bureau of Mines reports on methods, practices, and costs of mining and milling throughout the United States.

The Iron Mountain operation is notable for its successful transition from open-pit to underground mining, for use underground of large earth-moving equipment, and for development of a multilevel room-and-pillar mining method.

Milling methods also have undergone transitions - from hand sorting and log washing in the early days to gravity concentration. Milling ultimately may include flotation to recover additional iron from products now discarded as tailing.

Several types of ore deposits have been mined since the first recorded production in 1844, including surficial hematite-bearing residual clays, hematite boulders in porphyry conglomerate, and replacement and vein deposits in porphyry. Two ore bodies of the replacement and vein type were mined underground in 1955-56.

All the mined ore is upgraded to produce marketable concentrates in the company's mineral-dressing plant, which consists of jig and table units and an experimental flotation unit that treats the table tailing.

ACKNOWLEDGMENTS

Acknowledgment is made to R. C. Fish, vice president, Hanna Coal & Ore Corp., for permission to obtain and publish the operational and cost data presented in this paper.

Special acknowledgment is made to Floyd H. Lee, superintendent, for his cooperation and assistance; and to the entire group of department heads at Iron Mountain for contributions of pertinent information and assistance in preparing data and maps.

LOCATION AND PHYSICAL FEATURES

The Iron Mountain mine is in the S1/2NW1/4 and the N1/2SW1/4, sec. 31, T. 35 N., R. 4 E, St. Francois County, Mo. (fig. 1). The mine surface plant and concentrator are 1/4 mile north of the small town of Iron Mountain (300 population), through which runs the main line of the Missouri Pacific Railroad from St. Louis to the south (fig. 2). A 1/2-mile spur line of the railroad serves the plant. Paved county road W crosses the mine property and from there runs northeast 13 miles to Farmington and southwest 3-1/2 miles to a junction with State Highway 21.

The town and mine were named after Iron Mountain, a hill of igneous rock that rises about 400 feet above the adjacent valleys to an altitude of 1,450 feet. Big Mountain is a southern, lower extension of Iron Mountain, and Little Mountain is a

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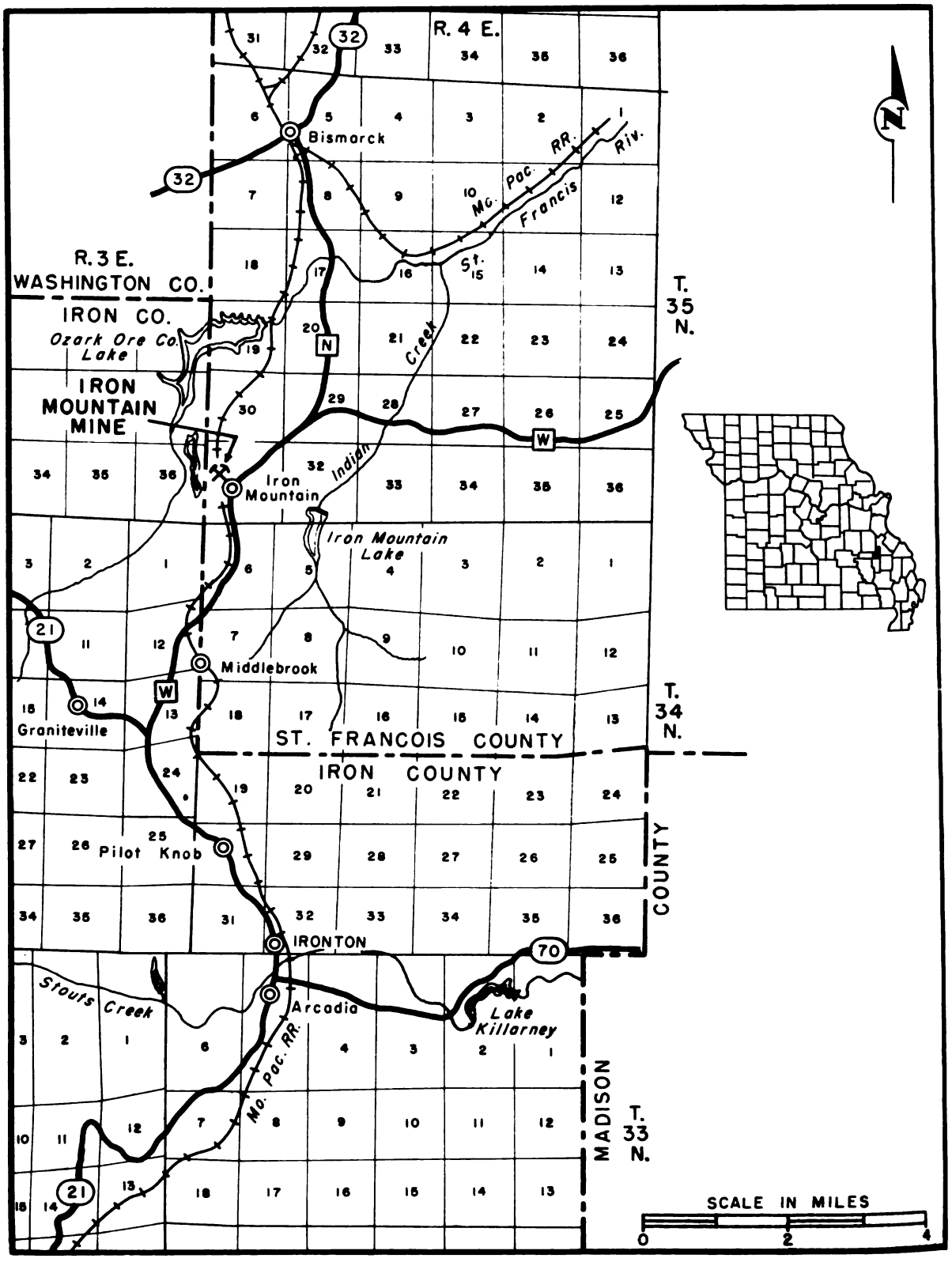

Figure 1. - Location map, Iron Mountain iron-ore mine, St. Francois County, Mo.

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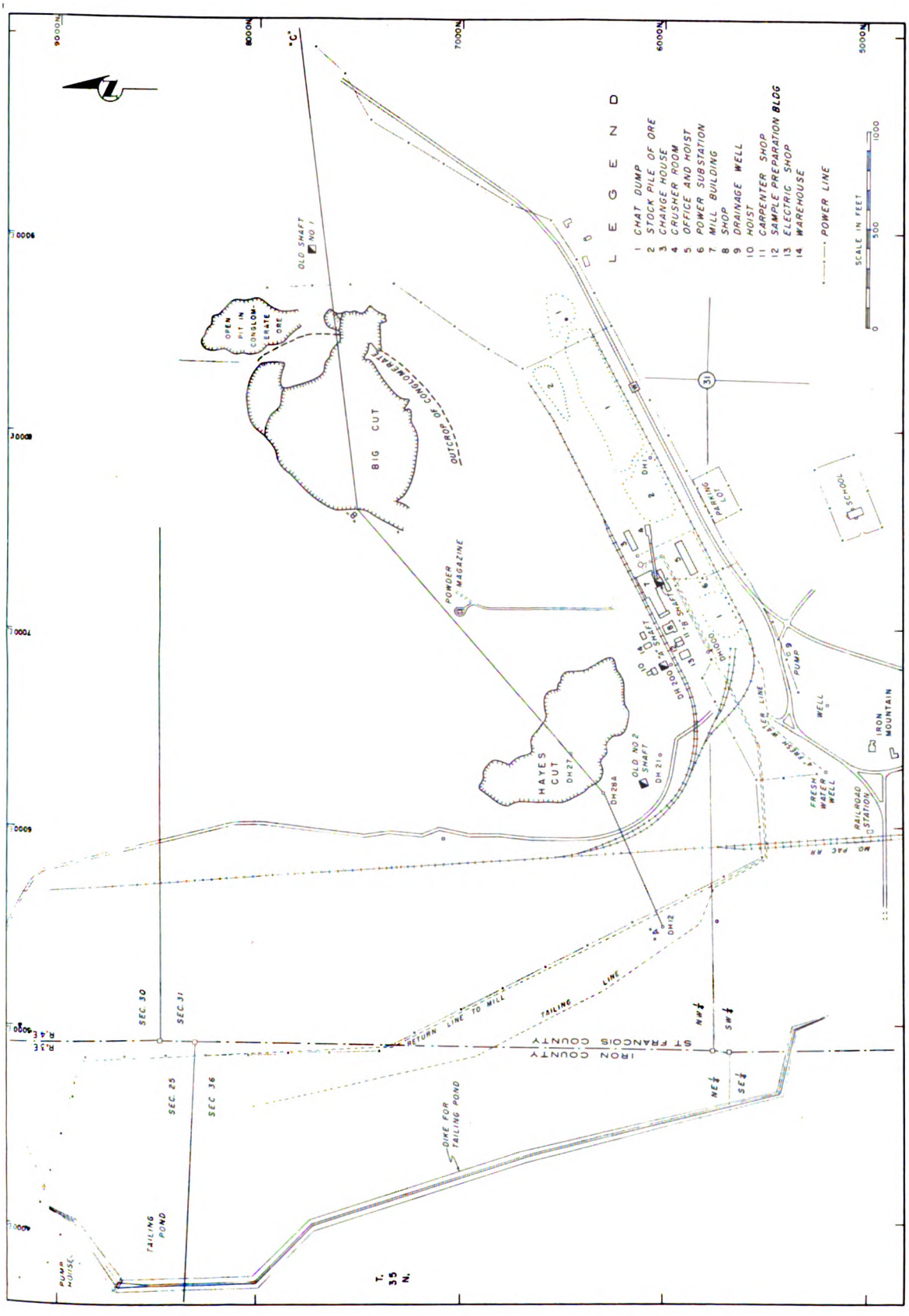

Figure 2. - Plan of surface plant and open pits.

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western nose of Big Mountain. The first iron-ore discovery at Iron Mountain was made on Big and Little Mountains, and all the known ore bodies except one on the property occur within them. The collar of the hoisting shaft is on the valley floor to the south at an altitude of 1,084 feet.

The mine is in a region of rounded hills and wide valleys. The climate is mild, with an average mean annual temperature of 59° F.; the extreme range since 1910 has been between minus 25° and 110° F. Normal precipitation is about 45 inches a year.

HISTORY

The first title of record to Iron Mountain was grant dated October 17, 1797, from the Spanish Government to Joseph Pratt in recognition of his services in public relations with the Indians of the Mississippi River Valley. Subsequently, title to specific parts of the grant was vested in a succession of persons and firms until the property was acquired in 1844 by American Iron Mountain Co., which mined boulders of hematite ore in that year and thus became the first ore producer of record.

Production reportedly was more or less continuous from 1844 to 1909, when the mine closed. Mining was resumed in 1920 by Leonard A. Busby, who acquired title to the property and made the first large-scale efforts to mine the low-grade ore deposits in porphyry, producing ore both from an open pit and underground. The mine was sold in 1927 to Missouri Ore Co., in which M. A. Hanna Co. had an interest. Low metal prices forced closing of the mine in 1930. The property was acquired in 1935 by Ozark Ore Co., a subsidiary of M. A. Hanna Co., and open-pit mining was resumed in 1944. Foreseeing exhaustion of ore amenable to mining by open-pit methods, the company reintroduced underground mining in August 1951; thenceforth, the proportion of ore mined underground increased each year until 1954, when open-pit operations were stopped.

During the productive life of the mine several distinct types of ore bodies have been mined. At the beginning, loose boulder ore was hand-sorted from residual clays on Big and Little Mountains. The sorted ore was transported by inclined tramways to the bottom of the mountains, thence by wagons to a nearby furnace and foundry. Hand sorting soon gave way to washing, which permitted mining hematite-bearing clays and conglomerate ore. Then followed the mining of ore in place in porphyry, concurrent with mining bedded conglomerate ore that extended downdip beneath sedimentary rocks. The decade 1920-30 saw the earliest underground operation in porphyry ore. The permanence and stability of the old stopes influenced choice of the present mining method.

Mineral dressing of the mined ore progressed from the simple hand-sorting and log-washing methods of the early days to the current practice of gravity concentration by jigs and tables.

In 1944 the concentrating plant, which had employed crushing and jigging to upgrade ore mined during earlier periods of operations, was rehabilitated, in conjunction with the resumption of large-scale mining on the property. The plant was again modernized in the early part of 1951. A pilot flotation section is now being used experimentally to treat part of the table tailing.

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Both hand-sorted ore and concentrates were smelted in local blast furnaces from 1846 to 1877 (1).3/ Since then most of the concentrates have been shipped to Granite City, Ill. Railroad transportation was first available to the region in 1858. The then St. Louis, Iron Mountain & Southern Railway Co. has since become a part of the Missouri Pacific system.

Recorded shipments of usable iron ore, including hand-sorted ore and concentrates, are shown in table 1.

TABLE 1. - Recorded shipments of iron ore

Years	Usable ore and concentrates shipments in long tons	Grade, percent of natural iron
1844-1943	4,534,173 (a)(b)	
1944-50..	924,917 (b)(c))	
1951.....	152,446 (c))	52.80
1952.....	232,518 (c))	
1953.....	239,830 (c)	53.11
1954.....	144,680 (c)	52.81
1955.....	208,007 (c)	54.15
1844-1955	6,436,571	

(a) Crane (2).
(b) Missouri Geological Survey.
(c) Ozark Ore Co.

DESCRIPTION OF DEPOSITS (2-6)

The geologic formations associated with or overlying the ore bodies at Iron Mountain are Precambrian andesite porphyry (5, 6), conglomerate of Precambrian or early Cambrian age, and Cambrian sedimentary rocks. The prophyry projects through the Cambrian rocks to form Iron Mountain and its southern extensions, Big Mountain and Little Mountain (fig. 3). The sedimentary rocks include the conglomerate, which may have been formed in the same period as the Cambrian LaMotte sandstone or earlier, and bedded shale, sandstone, and limestone of the Bonne Terre formation. The bedded formations overlying the flanks of the porphyry hills have maximum dips of about 20° near the contacts but flatten at short distances from the hills.

The iron-ore deposits, Precambrian in age, were deposited from solutions as replacements of the porphyry and as filling in cracks and fissures. Concentrations of iron minerals in the porphyry formed four known, disconnected deposits of major importance. Another type of deposit, in bedded conglomerate, was formed from the debris from weathered outcrops of porphyry ore bodies. The five ore deposits were:

1. Big Cut ore body, which occurred at the peak of Big Mountain in the form of an inverted U. Each limb of ore was about 20 feet thick at the top and tapered out at depth. Opencut mining extracted first the high-grade ore in these limbs; later, the pillar of porphyry between the limbs was mined. It was found to contain stringers and veinlets of hematite in enough concentration to constitute low-grade ore. This deposit had the most prolonged life of all the shallower ore bodies and was the source of much of the early ore production. It was depleted in 1951. In plan, the Big Cut pit is elliptical, 700 feet long and 500 feet wide (figs. 2 and 4). Mining extended to a depth of 170 feet. The weathered outcrops of the Big Cut

3/ Underlined numbers in parentheses refer to citations in the bibliography at the end of this report.

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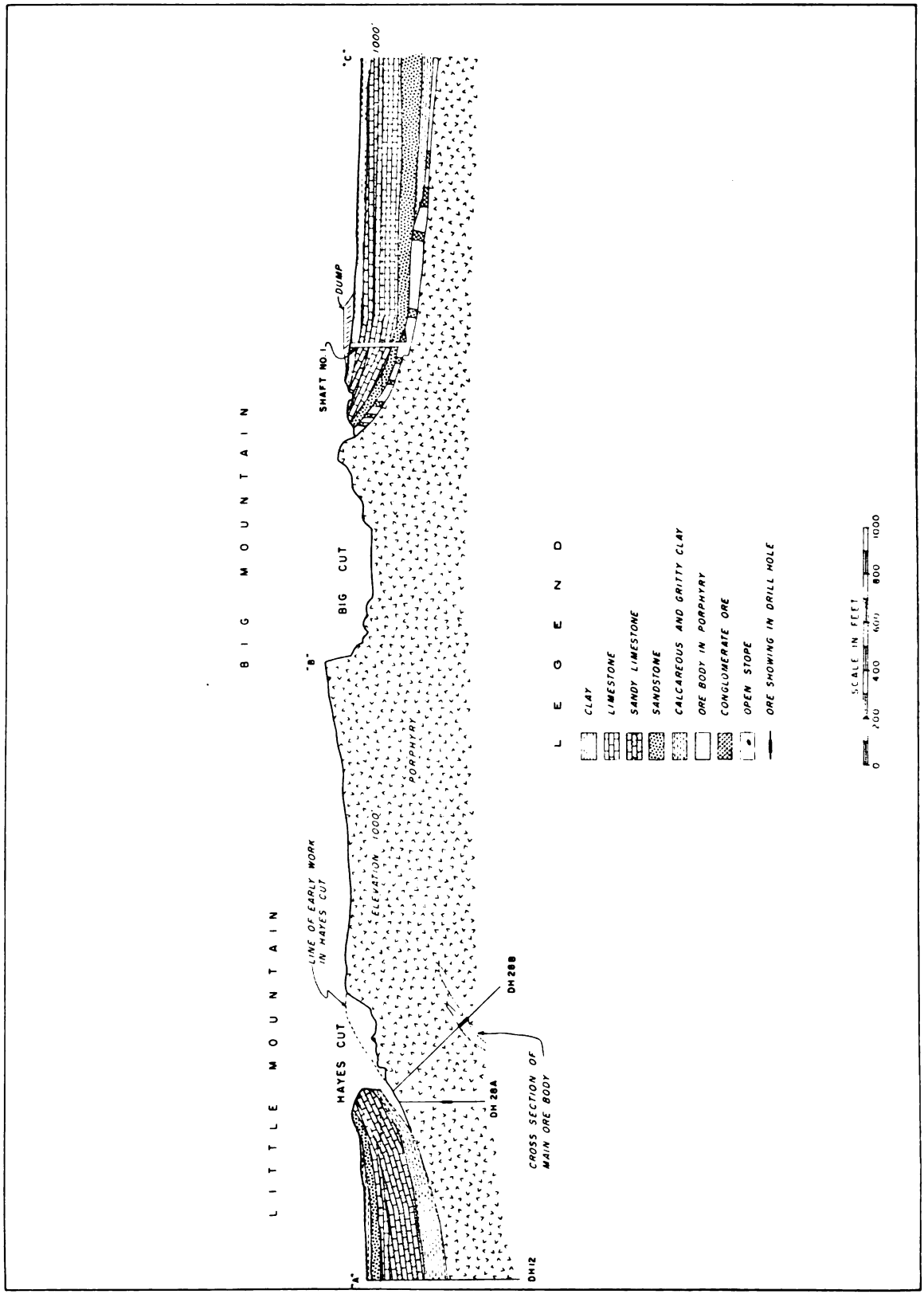

Figure 3. - Section ABC (fig. 2) through Big and Little Mountains.

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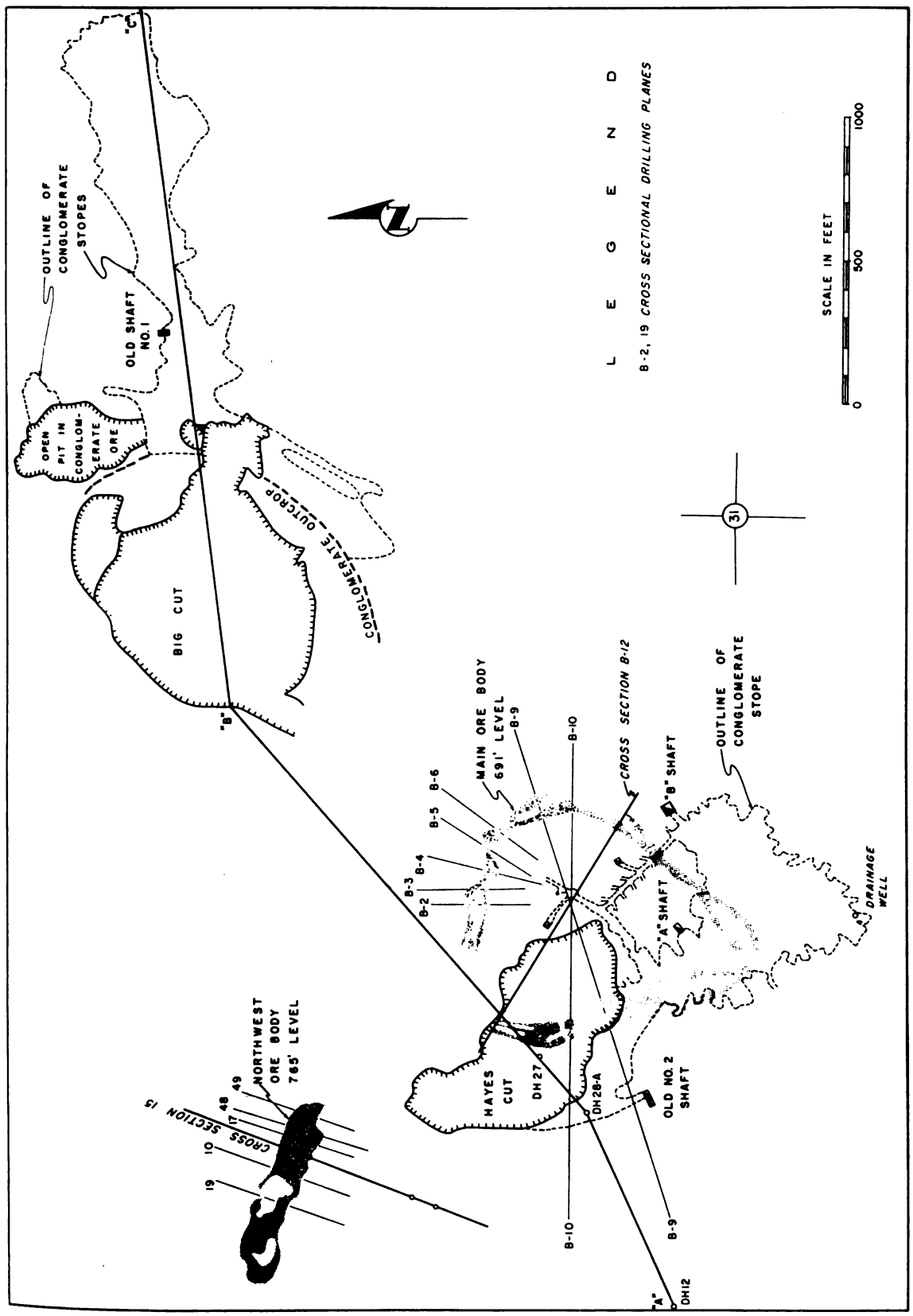

Figure 4. - Outlines of porphyry ore bodies in relation to the open pits and conglomerate stopes.

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and similar ore bodies were residual clays containing grains, nodules, and boulders of hematite. It was from these clays that iron ore was first produced at Iron Mountain.

2. Conglomerate ore bodies. The largest ore body of this type was in a bed of porphyry conglomerate that apexed against the Big Cut ore body on the east slope of Big Mountain. The conglomerate lay directly upon the uneven surface of the porphyry and was overlain by beds of sandstone and limestone (fig. 3). The ore, which consisted of fragments and boulders of specular hematite embedded in hard, gray arkose, ranged in thickness from 7 to 40 feet. Mining in this conglomerate progressed 1,500 feet eastward from the outcrop, and stoping widths averaged about 200 feet (fig. 4). The ore body dipped about 20° at the apex but flattened to the east.

The ore bodies near Big Cut were first mined before the Civil War and were depleted in 1910.

3. Hayes Cut ore body. The ore mined first in Hayes Cut was from a conglomerate similar to that adjacent to Big Cut. The conglomerate ore had a maximum thickness of 40 feet and was mined to some extent before 1910. The major part of the ore produced during the period 1920-30 was mined from the conglomerate (figs. 3 and 4). Hayes Cut was deepened, when open-pit mining was resumed in 1944, to mine the porphyry ore below the conglomerate.

4. Main ore body, which is about 1,000 feet southwest of Big Cut and underlies part of Big Mountain and part of the valley to the south. It also underlies part of Hayes Cut (fig. 4). The deposit is a dome-shaped shell of ore in porphyry, completely roofed over but open at the north end below the top of the dome. The walls of the ore body are very irregular, both in plan and section (figs. 4 and 5). The distance between the inner and outer limits of minable ore usually ranges from 40 to 100 feet but may be as much as 200; in some sections the limb of ore is too narrow to be mined. Large horses of waste or low-grade ore are scattered through the deposit. One or both walls of the ore body are well-defined in some places; in others the massive ore blends into breccia containing stringers and veinlets of hematite, and stoping limits are determined by the grade of ore. Mining in the Main ore body began in the 1921-30 decade, and the arch of the dome was nearly mined out by the end of that period. Underground mining was resumed in this ore body in 1951.

5. Northwest ore body, which is about 600 feet northwest of the Main ore body (fig. 4). This deposit is about 650 feet long and 100 feet wide and occurs in the porphyry. The apex of the main mass of ore is about 250 feet below the surface, and the vertical range of the ore averages about 200 feet (fig. 6). Ore was discovered here before 1910 in a drill hole, but the ore body was not explored until the late 1920's. Development began in 1952 from crosscuts driven to it from the Main ore body. Irregular horses of waste also occur in the Northwest ore body.

The chief ore mineral in the Iron Mountain deposits is a hard, blue specular hematite. Magnetite occurs sparsely in the eastern and southern parts of the Main ore body but is virtually absent in the Northwest ore body. The maximum ratio of magnetite to hematite in the Main ore body is 1 to 4. Gangue minerals include andradite garnet, tremolite and actinolite amphiboles, chlorite, quartz, and apatite (2-4). The country rock is fine-grained andesite (5-6), porphyritic in places. It is referred to throughout this paper as porphyry.

The ore is hard and dense. The specific gravity of high-grade ore is 4.70, whereas that of the porphyry is 2.67. The factor used in computing ore tonnages is 224 pounds per cubic foot.

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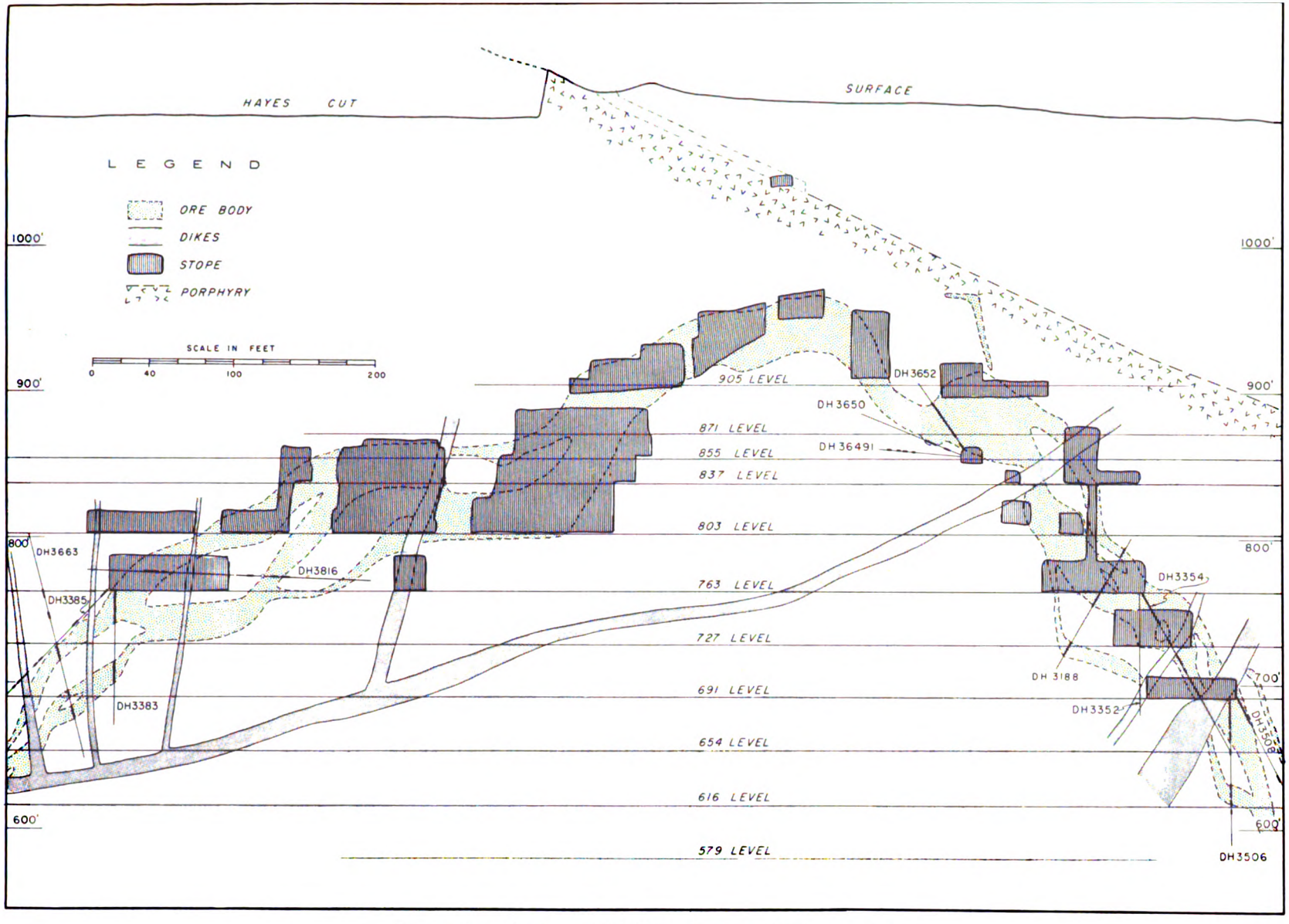

Figure 5. - Section B-12 (fig. 4) across Main ore body.

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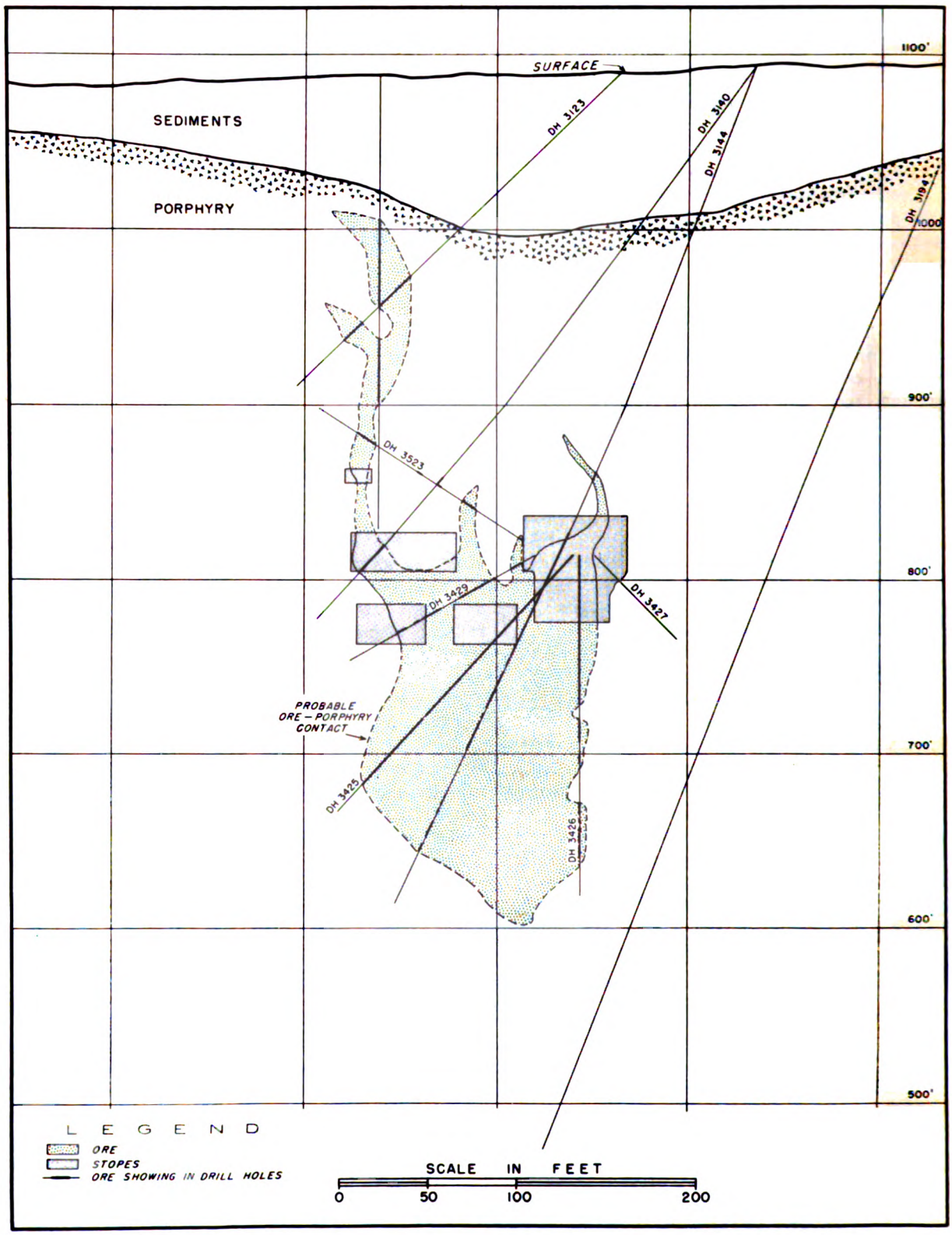

Figure 6. - Section 15 (fig. 4) across Northwest ore body.

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A few minor postore faults and a network of postore trap and felsite dikes cut across the porphyry and ore bodies. Dips and strikes of the faults and dikes are variable, but the dips usually range between 70° and 90°. The largest of the dikes, called "Big Dike," has a dip of about 30°. A joint system in the ore is usually keyed together enough to keep the backs and walls of stopes firm and free from sloughing.

METHODS OF PROSPECTING AND EXPLORATION

Prospecting for undiscovered ore bodies is carried on continuously. Magnetometer, gravity, resistivity, and induction surveys, followed by diamond drilling on indicated anomalies, are used in prospecting virgin areas.

Outlines of the Main and Northwest ore bodies are determined in advance of development by diamond core drilling. Holes are drilled from various levels at drill stations that are opened far enough outside the ring of the ore body to permit suitable angles of intersection between drill holes and ore zones. Two to six holes are drilled from each station. Stations are located and drill holes directed within planes of previously established cross sections, which are spaced at intervals of about 55 feet along the ore body. The information obtained from drilling is used to determine the outlines of the ore body, in estimating quantities and grades of ore, and in making plans for developing and mining the ore blocks. All exploration is done by diamond drilling; thus no exploratory crosscuts other than drill stations are driven.

Diamond drilling aggregated 89,000 feet of bore from 1942 to the end of June 1956. Of this total, 18,548 feet of hole was drilled in 1942 to prospect for and explore the subsurface ore bodies. This drilling campaign disclosed that the primary deposits of iron ore in the porphyry were much more extensive than previously presumed.

ORE ESTIMATION AND METHODS OF SAMPLING

Estimates of ore reserves are based on calculations of tonnage and grade of ore in blocks between cross sections previously explored by diamond drilling. Geologic data and assays of drill core samples are plotted on drawings of these cross-sectional planes. Although the shape of the ore body and the grade of ore are irregular, experience indicates that irregularities between cross sections plotted at about 55-foot intervals tend to offset each other and that closer spacing of drilling planes is not necessary or economically advisable. An included network of dikes is a factor in ore dilution that introduces a need for constant revision of ore estimates. Early estimates of the amount of dike material that would be encountered in the Main ore body have been greatly exceeded.

Assay samples from diamond-drill cores consist of half the split cores. Core samples are taken over each 5 feet, or at shorter intervals if there is a visible discontinuity in iron content or rock characteristics.

Sampling in the mine consists solely of taking grab samples from the top of each pile of freshly broken ore. The grab samples are not used for control of mining, as the character of each face may change abruptly in all directions. Underground control of stoping limits is a compromise between the previously planned limits and revisions by the mine staff, which visually checks each face carefully.

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The grade of ore mined and hoisted is determined daily from assays of the mill-feed sample. This sample is taken by a Hardinge automatic splitting sampler, following reduction of the ore to minus-1/2-inch in the secondary crushing plant. The monthly average grade of the muckpile grab samples is reasonably close to that of the mill-feed samples.

The crude-ore samples are analyzed only for iron content. Composite samples of 10-carload shipments are analyzed for iron, silica, phosphorus, and sulfur.

DEVELOPMENT AND MINING

Development

Inspection of the stopes opened in the upper part of the Main ore body between 1920 and 1930 had disclosed that the pillars, backs, and walls were still sound after standing at least 20 years. The apparent firmness of the ore and stability of the old workings led to the present plan of developing and mining the Main and Northwest ore bodies by an unusual multilevel room-and-pillar method (figs. 5-10).

Preparatory to developing the Main ore body on various levels, 1 of the 2 shafts (B shaft, figs. 4, 7, and 9) that had served the previous underground operations was deepened from the 837 level to below the 579 level. Mining levels were designated by their respective elevations above sea level. Shaft stations were cut on the 763, 691, and 579 levels; and crosscuts to the ore body were driven on the 837, 763, and 691 levels. Intermediate levels were developed at vertical intervals of 34 to 40 feet. The higher levels, which had been opened at irregular intervals during earlier operations, were incorporated into the mining system as levels 905, 871, 855, and 837. The ore body above the 905 level, which is near the roof of the dome, had been mined out, except for a small part in the northeast section. Ore had also been mined on the 871, 855, and 837 levels but to a smaller extent. Only about one-fourth of the available ore on the 837 level had been extracted.

The development of levels in both ore bodies is so much a part of mining that it is classed as such, rather than as development. Drifts are driven as full-size rooms, 24 feet high and 35 feet wide, except through dikes and narrow or very low grade ore zones where the size of opening is reduced to 16 by 18 feet, the minimum size that will permit operation of the rocker shovels.

Levels are interconnected by inclines, driven on slopes of 18° to 20° (fig. 9), mostly in waste. Inclines were driven 15 feet high and 18 feet wide at first; they were enlarged later to 16 by 18 feet to allow loading by rocker shovel. The inclines below the 691 level are driven 17 feet high and 22 feet wide to allow ample room for installation of belt conveyors and passage of mobile equipment.

The Northwest ore body is entered by crosscuts from the Main ore body on the 803 and 691 levels and by an incline from the 691-level crosscut to the 765 level. Part of the ore body above the 803 level is too narrow to be mined with mechanized equipment (fig. 6), so it is being mined by shrinkage stoping. Raises to the stope are 50 feet apart.

Inclines, diamond-drill stations, and raises are classed as development openings.

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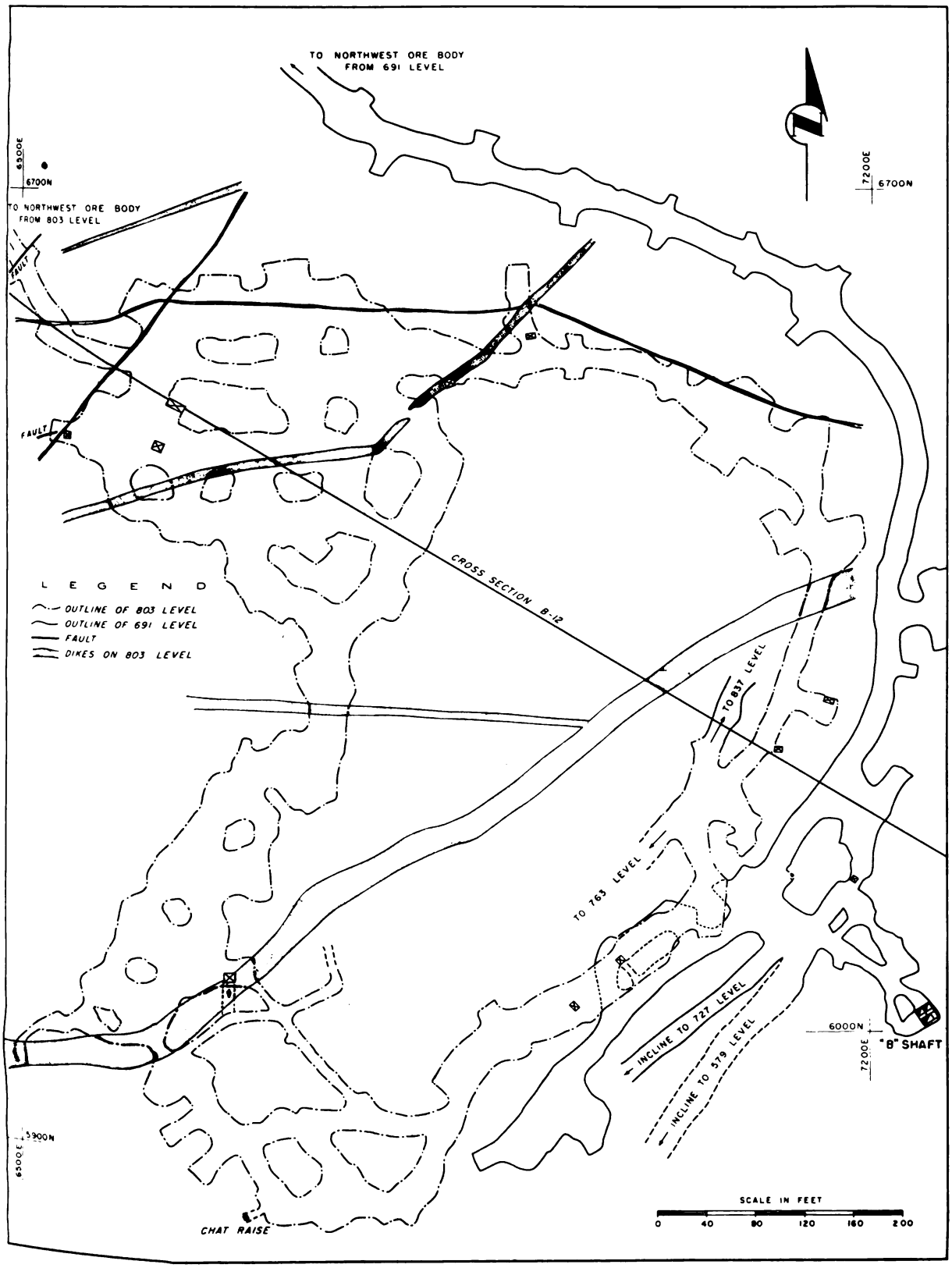

Figure 7. - Plan of 803 and 691 levels, Main ore body.

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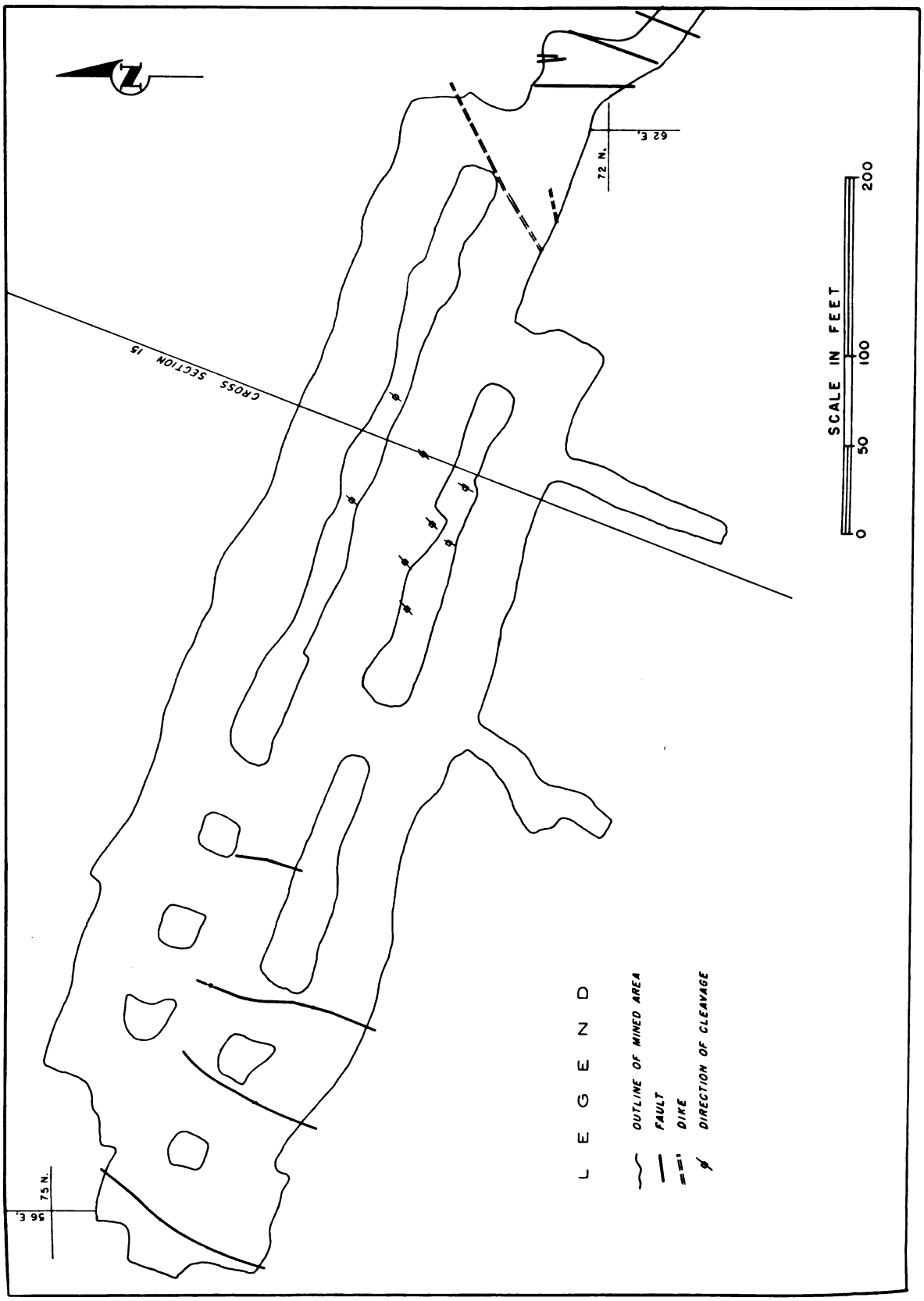

Figure 8. - Plan of 765 level, Northwest ore body.

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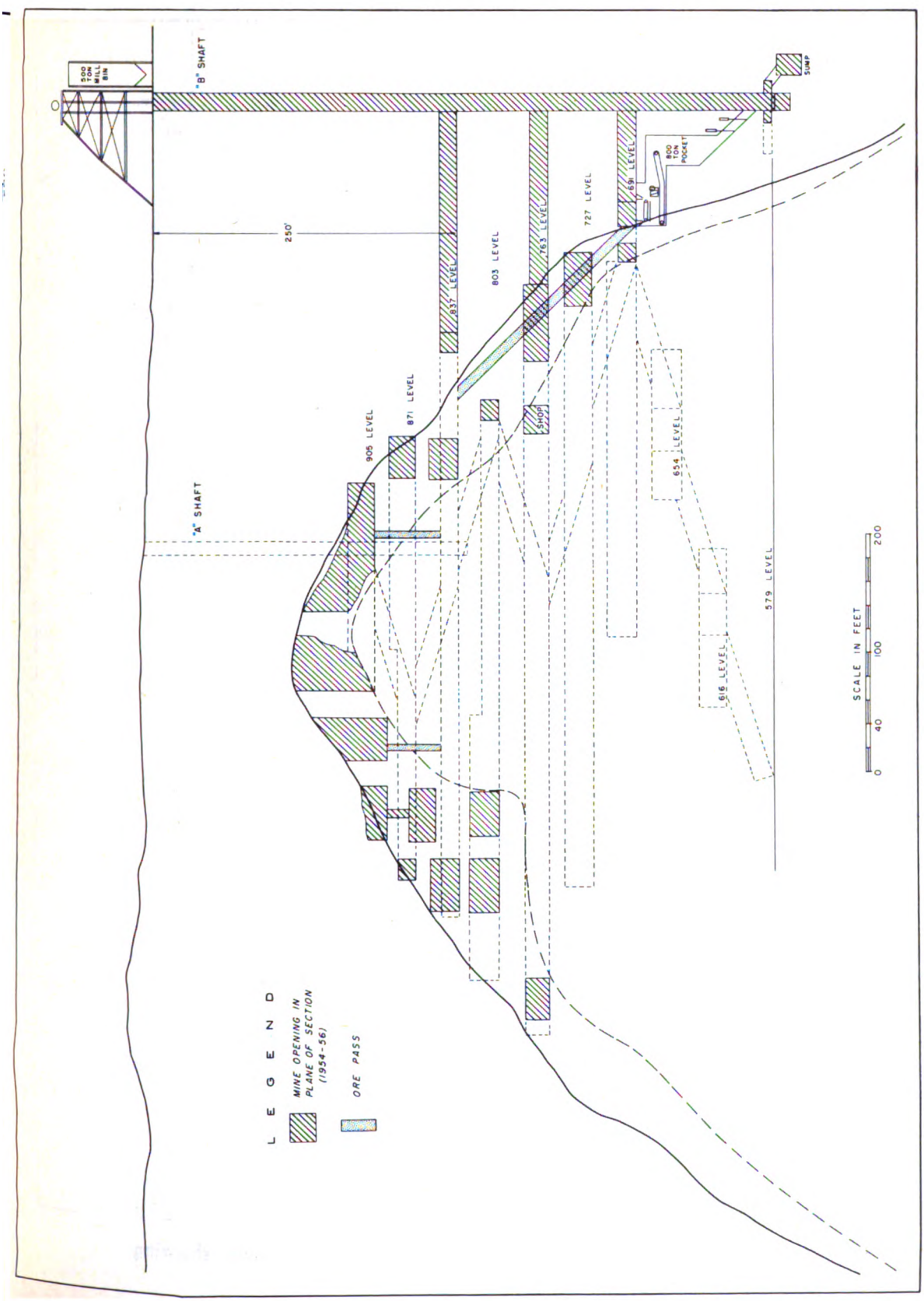

Figure 9. - Generalized section through B shaft and Main ore body.

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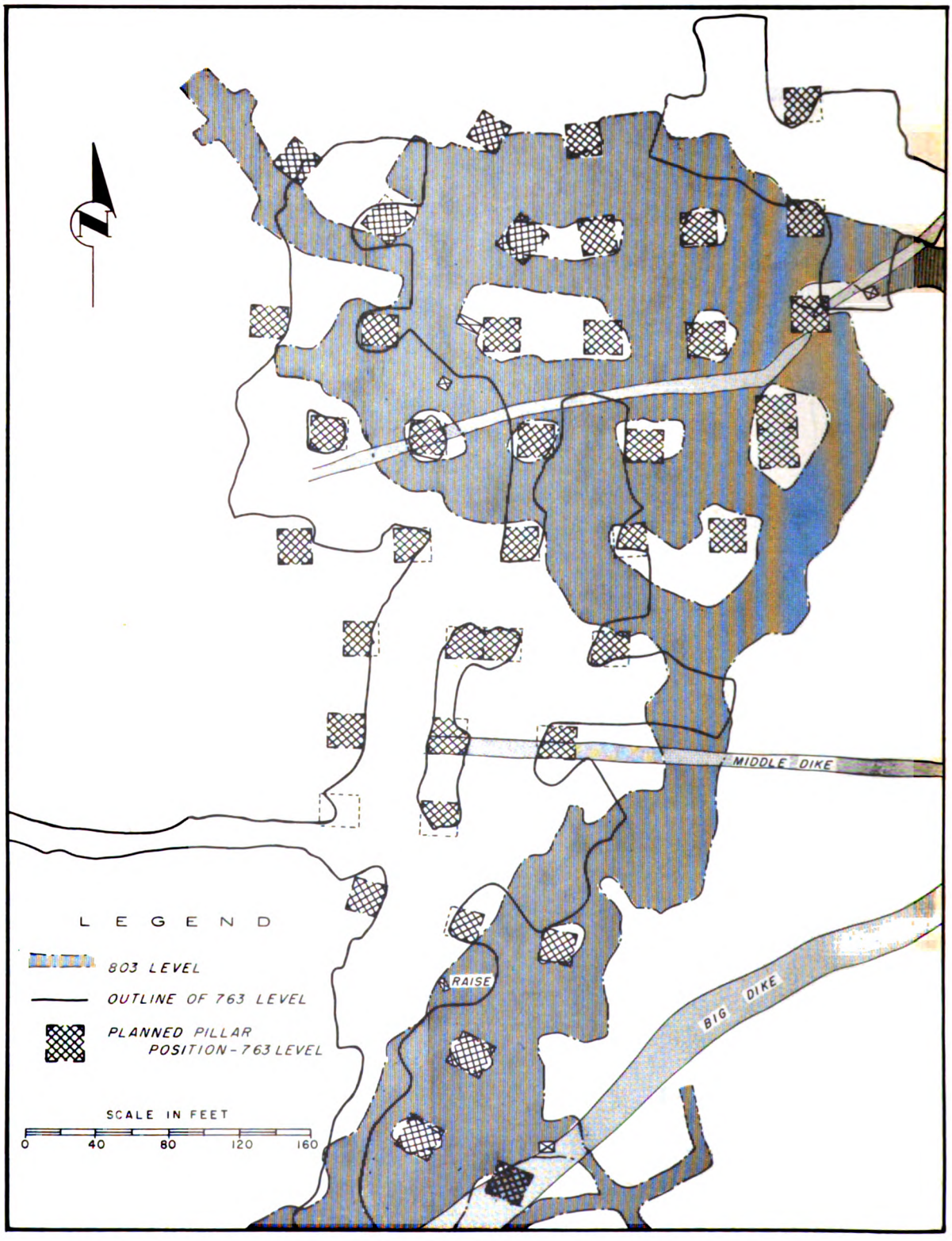

Figure 10. - Plan of part of 803 and 763 levels, Main ore body, showing proposed locations of pillars on 763 level.

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Mining

The basic plan of mining is the same for both the Main and Northwest ore bodies, although they are quite different in shape and structure. Marked variations from the basic plan are necessary in some places, particularly in the Main ore body.

Where the ore body is wide enough, 1 or more rooms (24 by 35 feet) are opened parallel to the development drift, with intervening 20-foot pillars (figs. 7 and 8). Full-size transverse rooms, or "breakthroughs," are driven on 55-foot centers, leaving a pattern of rooms 35 feet wide and pillars 20 feet square.

The irregularities in shape and grade of the ore bodies require some flexibility in the pattern. In places, therefore, room widths may be reduced, or breakthroughs may not be driven. The spacing of pillars may be altered to permit locating them in waste or low-grade ore.

As each new level is mined, care is taken to spot the pillars directly below those of the level above (fig. 10), except in parts of the Main ore body where the dip and thickness of the ore are such that the lateral overlap of levels is small.

Drilling

Drilling is done with percussion rock drills mounted on 2-drill jumbos of 2 sizes.

The smaller jumbos, 3 in number and each operated by a 2-man crew, can drill faces up to 18 feet in height. They are mounted on rubber tires and driven by air motors. Two hydraulic booms, mounted at the forward end of each jumbo, support the drills. The drillers' platforms are supported by and fixed parallel to the booms. Boom controls are near the platforms.

The larger jumbos are operated by 3-man crews, each comprised of 2 drillers and a helper. The helper positions the jumbo and otherwise assists the drillers. These jumbos, which can drill faces up to 24 feet in height, are crawler-mounted and driven by two 7-1/2-horsepower electric motors, one for each track. Each of the four jumbos in use is equipped with a folding tower (fig. 11), which is lowered to a horizontal position when the jumbo is moved from place to place. The tower is raised and lowered hydraulically. The 2 hydraulic booms that support the drills are mounted on a central platform, which is raised or lowered on the tower within a range of about 12 feet by a 5-horsepower electric motor. Drillers' platforms are suspended below crossarms on gimbals so that they will remain level, regardless of the position of the booms. Controls for movements of the central platform and tower are on the chassis of the jumbo; duplicate platform controls and the boom controls are near the drillers' platforms.

The jumbo-drill round is semistandard in design. The basis of the round is a vertical wedge cut toward one side of the face, with other vertical rows of holes gradually angling away from the wedge until the direction is perpendicular to the face (fig. 12). The normal round has 12 vertical rows of holes and 6 horizontal rows. At times seven horizontal rows are drilled. In some rounds two helper holes are drilled in the center of the wedge, converging toward each other in a vertical plane. Jumbos usually are operated in pairs in the rooms. The 2 drilling crews drill a nominal 10-foot round of 72 to 84 holes and load it for blasting in 8 hours.

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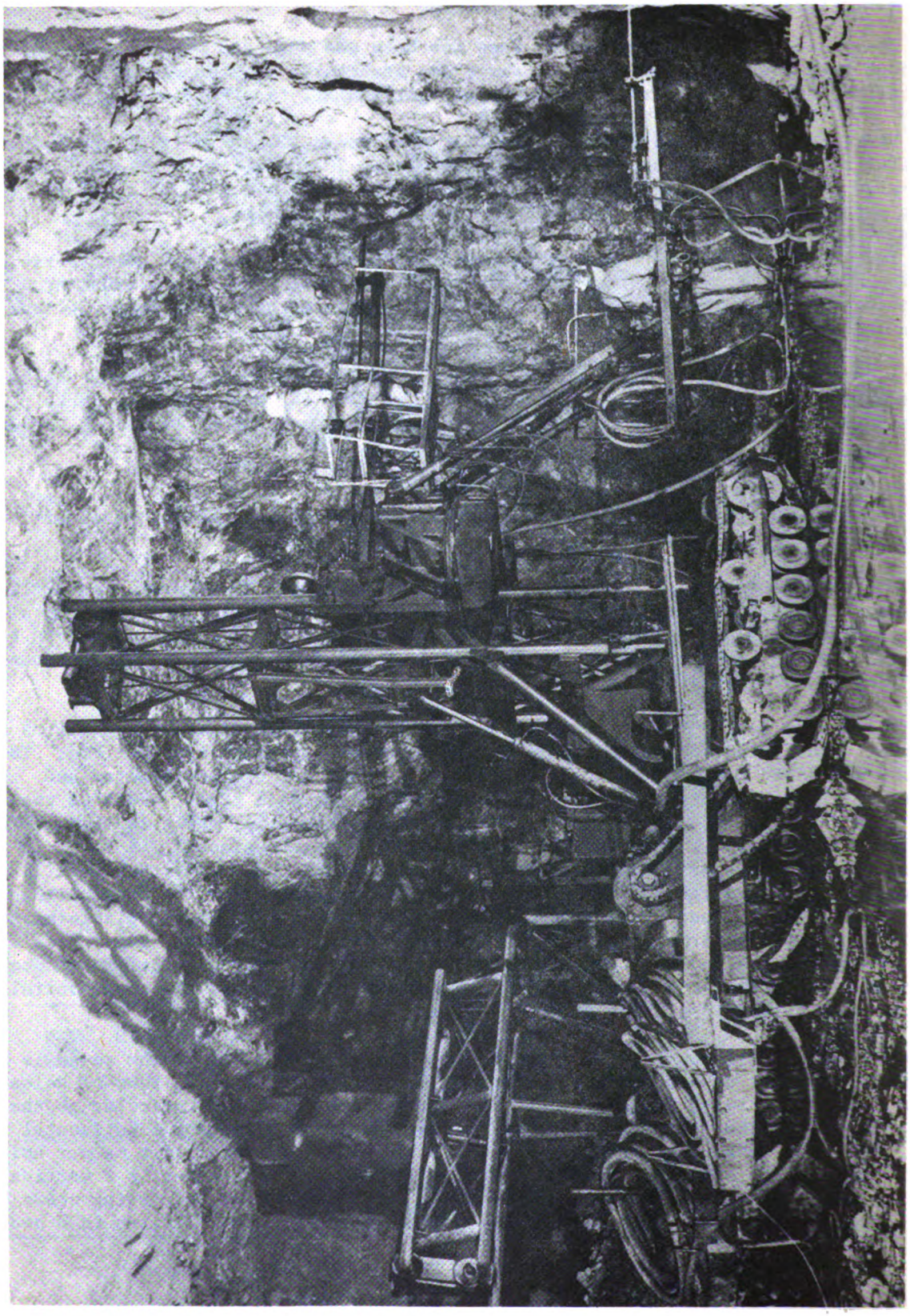

Figure 11. - Drill jumbo with adjustable tower.

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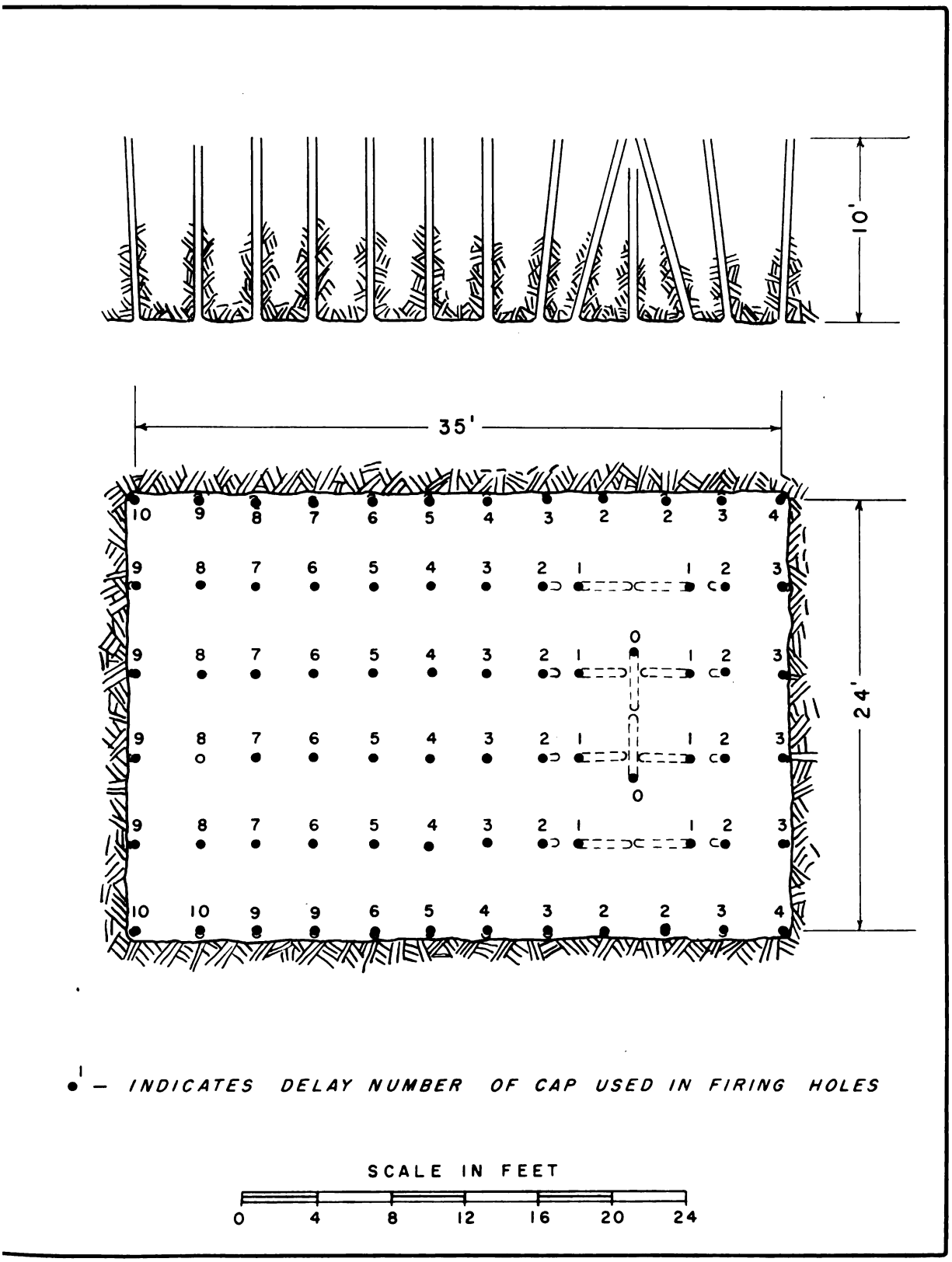

Figure 12. - Wedge-cut jumbo drill round.

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The rock drills are 3-1/2-inch drifters, chain-driven by air-feed motors along 13-foot sashes mounted on the boom arms of both types of jumbo. The drills use 1 1/4-inch, round carbon steel in lengths of 9 to 18 feet, with detachable 1 7/8-inch tungsten carbide bits. Holes are drilled to the full depth of the face round and up to 15 feet in the occasional slabbing round without change of steel or bits. Rock penetration ranges from 6 to 12 inches per minute, with an air pressure of 75 pounds per square inch at the drills. The average footage drilled per machine shift is 160.

Drill steel is purchased in bars 30 to 36 feet long and cut into 13- to 18-foot lengths at the mine. Broken steel is reshanked or rethreaded and used again until it becomes shorter than 9 feet. Breakage usually occurs within 1 foot of the shank or bit ends. The average life of a drill steel before discarding is about 540 feet of hole drilled. Discarded pieces of drill steel, in lengths less than 9 feet, are re-formed into wedge bolts, hangers, and other useful shapes.

Drill bits are 4-wing tungsten carbide insert bits with 1 center hole and 2 side holes. Bits are reground after drilling about 30 feet, and the total bit life is about 300 feet. The bits are not resized when they are reground, as the loss of gage is too small to be measurable. This unusual behavior in hard, abrasive ore may be due to the bit design, which is featured by a taper of only 1/8 inch from the tip of the base of the body of the bit.

Blasting

Holes are loaded for blasting with semigelatin dynamite of 55-percent strength. The drillers load the holes from the drilling platforms of the jumbos after moving the drills to their rear positions. The blasting charge comprises about one 1-1/8-inch cartridge of dynamite per foot of hole. Blasting an average round advances the face about 8 feet and breaks about 660 tons of ore.

Instantaneous and regular delay electric blasting caps, fired through a 220-volt blasting circuit, are used to detonate the explosive. As a safety precaution, two switches are used in firing a round. The first switch, about 300 feet from the face and always in a protected place, is closed by the drillers as they leave at the end of the shift. The second, or firing switch, is closed by the mine shift boss. Electric current for blasting is supplied from a separate transformer.

Virtually no secondary blasting is done. Whenever it is necessary, such blasting is done by mudcapping with a small part of the dynamite cartridge.

Trimming

Walls and backs are trimmed mainly from mobile machines equipped with platforms that can be raised to required heights. These trimmer machines (2 small and 1 large) were designed and built, except for the chassis and motors, at the mine. The smaller machine is equipped with a hand crank for raising and swinging the platform. The platform of the larger machine (fig. 13) is raised hydraulically and turned by compressed air.

The trimming crews, each of which consists of 2 trimmers and 1 driver, trim the walls and backs after the rounds have been blasted and the broken ore or waste has been loaded. They also constantly check the backs in all parts of the mine. Hand-scaling bars and 18-pound, nonrotating pneumatic hammers are used for trimming.

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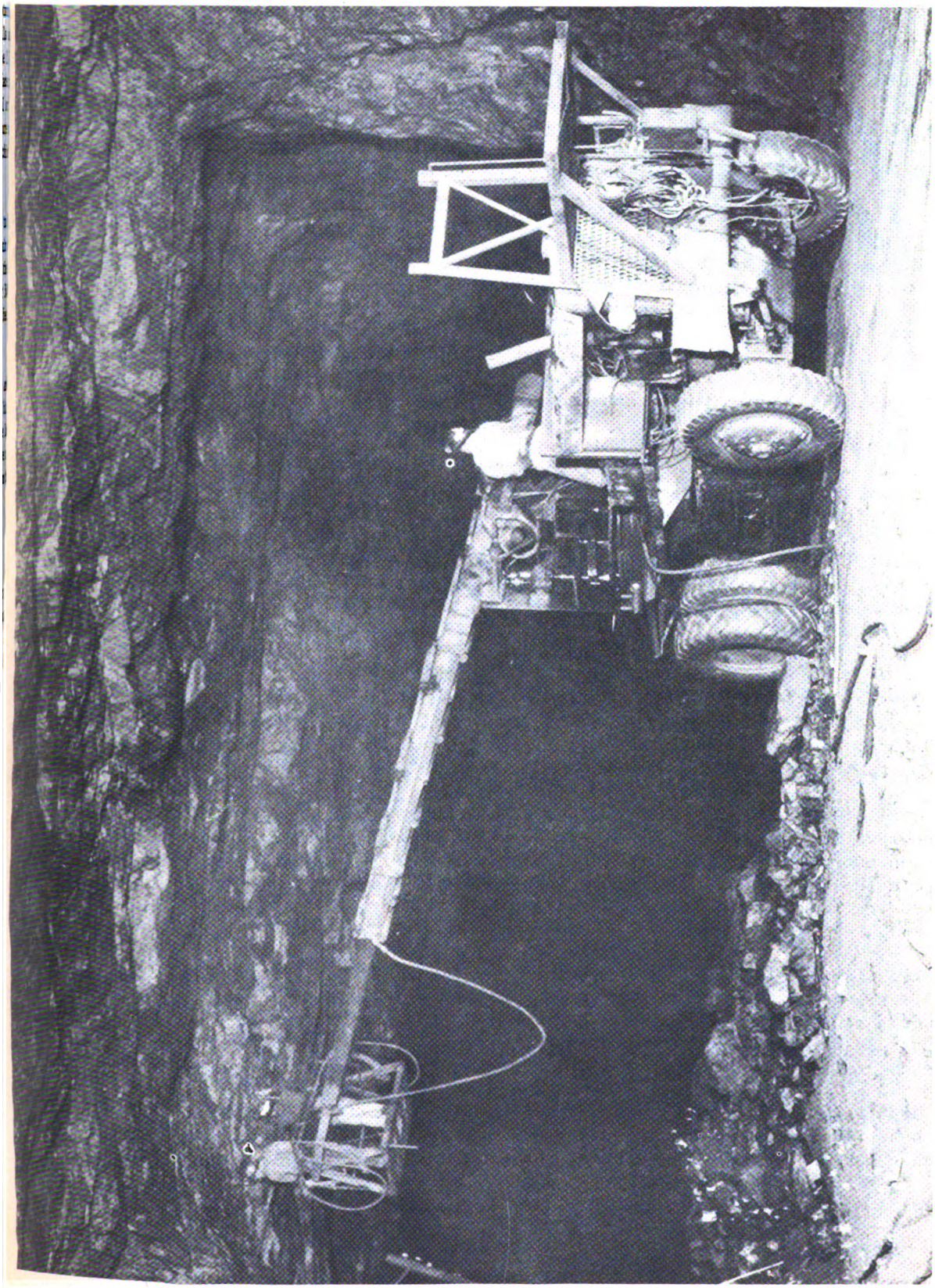

Figure 13. - Large trimmer machine.

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Clean backs and solid ribs are maintained, except for a few places where horizontal joints in the ore have made the backs so slabby that stability has been difficult to achieve. Roof bolting is used in these places if necessary and feasible. A few catwalks have been built in the higher stopes where the backs are above the reach of the trimmer machines. The catwalks are supported on eyebolts wedged into holes drilled into the back for this purpose.

Only one large rock fall has been reported.

Loading

Broken ore and waste are loaded by electric dipper shovels (fig. 14) and rocker-arm loading machines. Three 3/4-yard shovels, two 1-yard loaders, and two 1-1/2-yard loaders are in use. One of the larger loaders, driven by a 125-horsepower diesel engine, was added in the latter part of 1956. The dipper shovels are powered by 40-horsepower, 440-volt, alternating-current induction motors. The smaller loaders and the other 1-1/2-yard loader are powered by 45- and 83-horsepower diesel engines, respectively. Both the shovels and loaders are crawler-mounted.

The electric shovels were built with 18-foot booms and 14-foot dipper arms. One shovel was modified at the mine to operate with a 14-foot boom and a 12-foot dipper arm. This machine is used in lieu of rocker loaders in the smaller openings and is also used in intermediate-sized (18- by 26-foot) stopes.

Electric shovels usually load at a rate of 120 long tons per hour but have a slightly higher capacity. The larger rocker loaders operate at about the same rate as the shovels, whereas the smaller ones load at about two-thirds the rate.

Underground Transportation

Ore is loaded into diesel-powered gravity-dump trucks (fig. 14) for haulage underground. The rated capacity of the trucks is 8 tons, but the usual load is 9 to 10 tons, due to the density of the ore. The electric shovel, with its accurate placement, loads to about 10 tons.

Ore is hauled on the 691 level to a small crusher-feeder pocket near B shaft and on levels above the 691 to ore passes that connect with the feeder pocket (fig. 9). The bottom of this pocket is an apron feeder 60 inches wide, which conveys the ore to a 30- by 42-inch split-frame jaw crusher set for 5-inch discharge. The crushed ore is conveyed to an 800-ton storage pocket, below which are 2 skip-loading pockets.

Revision of the ore-handling system is planned to provide for movement of ore from levels below the 691 to the storage pocket at the shaft. The revision does not include further shaft sinking. The crusher is to be moved to the 579 level and the ore-pass system extended to the new crusher-feeder pocket. Crushed ore will be moved by conveyor belts to the existing storage pocket.

Underground roads are constructed mainly of mill "chats." Coarser rock is used as a base in areas where an unusual amount of water is present in the haulageways. The chat is transferred from a storage pile on the surface through a 9-inch churn-drill hole to the 871 level. From there it is moved to lower levels through a system of raises that extends to the 616 level.

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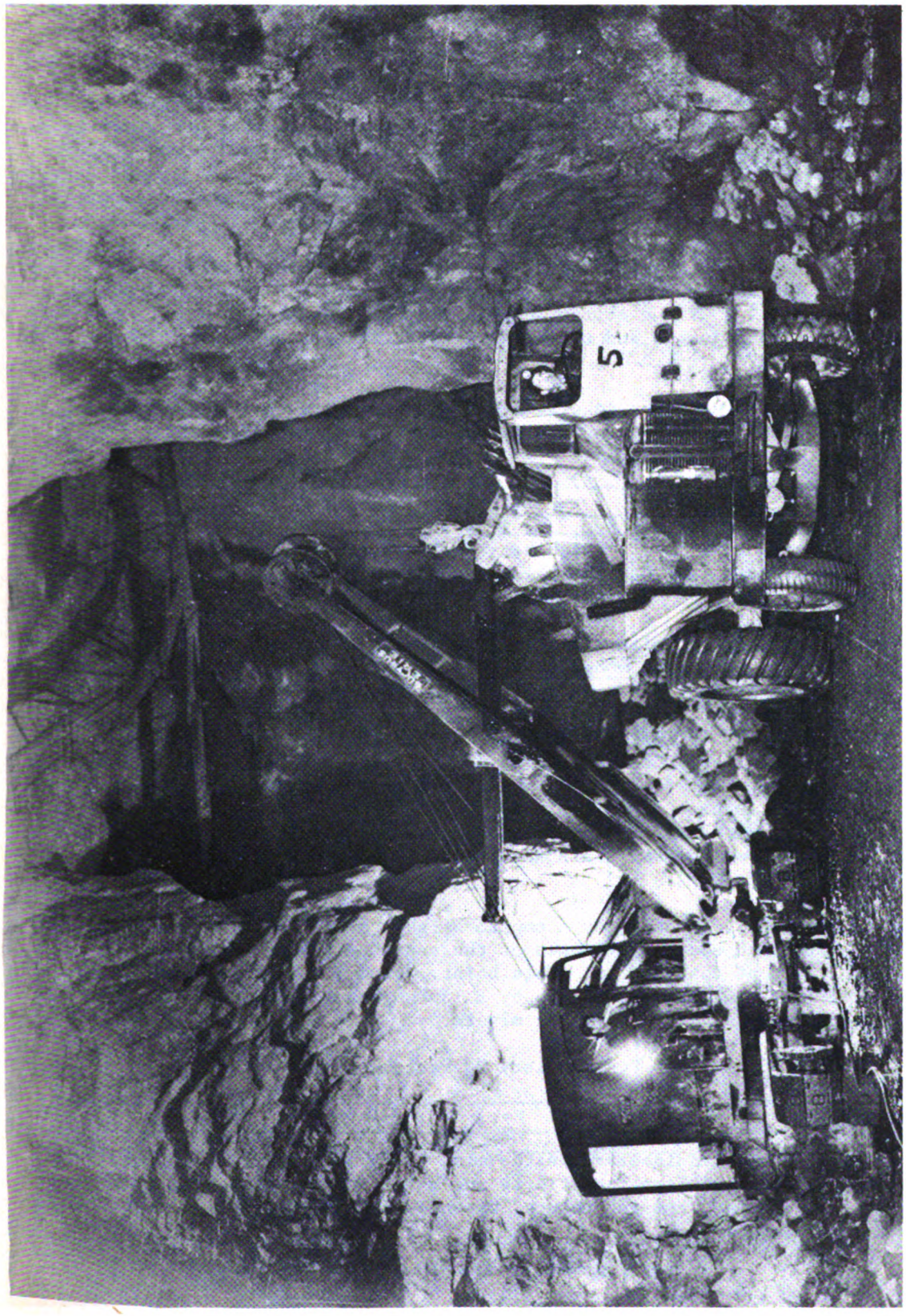

Figure 14. - Electric dipper shovel and 8-ton diesel truck.

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Road construction consists of loading the chat by rocker shovel into a truck, hauling and dumping it along the haulageway, and spreading by bulldozer to a thickness of 1 foot. A drainage ditch is left at one side of the road. The roads are built to within 50 or 100 feet of the active faces.

Road maintenance throughout the mine is done weekly; chat is added to the roadbed as needed, surfaces are leveled with a drag, and backblading is done with a bulldozer. The complete operation requires about 5 hours. The chat forms a strong roadbed and resists pulverizing. Haulageways are never dusty. The tire cost - $.0147 per long ton of ore hauled - attests to the excellence of the roadbeds.

All mobile equipment travels under its own power. Speeds range from 15 to 18 miles per hour for trucks and average 8 and 6 miles per hour for tractors and rocker loaders, respectively. The electric shovels travel at a rate of about 1 mile per hour and the drilling jumbos and trimmer trucks at rates ranging from 1 to 8 miles per hour.

A winch truck is used for general service and for transporting supplies and explosives. A personnel car is available for use by the mine foreman and shift bosses.

Hoisting

Ore is hoisted at B shaft, which has five compartments framed with steel shaft sets. Two compartments are for the skips and one each for the cage, cable and pipe, and manway (fig. 15).

Skips are hoisted in balance, without the use of a tail rope. The 1 1/8-inch, steel-wire hoisting ropes are wound on a cylindrical single-drum hoist, which has a double reduction gear and standard Lilly overspeed and overwind controls. Drum diameter is 6 feet. The hoist is driven by a 250-horsepower, 2,300-volt electric motor. Rope speed is 500 feet per minute. Kimberley-type, 5-ton overturning skips are loaded from the 2 skip pockets, which are controlled by vertical, air-operated, guillotine-type gates and dump into a 500-ton storage bin mounted in the headframe (fig. 16). A small bin at one side is so located that it receives the spillage if the main bin is overloaded. If the hoisting rate exceeds the milling rate, the excess ore is drawn from the small bin and hauled by a 20-ton end-dump truck to a stockpile.

The cage hoist is balanced by a counterweight that moves within a vertical pipe. The 1 1/8-inch steel-wire ropes of the cage and counterweight are wound on a cylindrical, 4-foot double drum. This hoist, which also has standard Lilly overspeed and overwind controls, is driven by a 150-horsepower, 2,300-volt, electric motor. Hoisting speed is 500 feet per minute.

Auxiliary Operations

General Services

A group of unskilled laborers in the mine is known as the "bull gang." The bull gang transports supplies, constructs and maintains ditches, checks and maintains ventilation structures and raises, extends air and water lines, and is used in general maintenance work.

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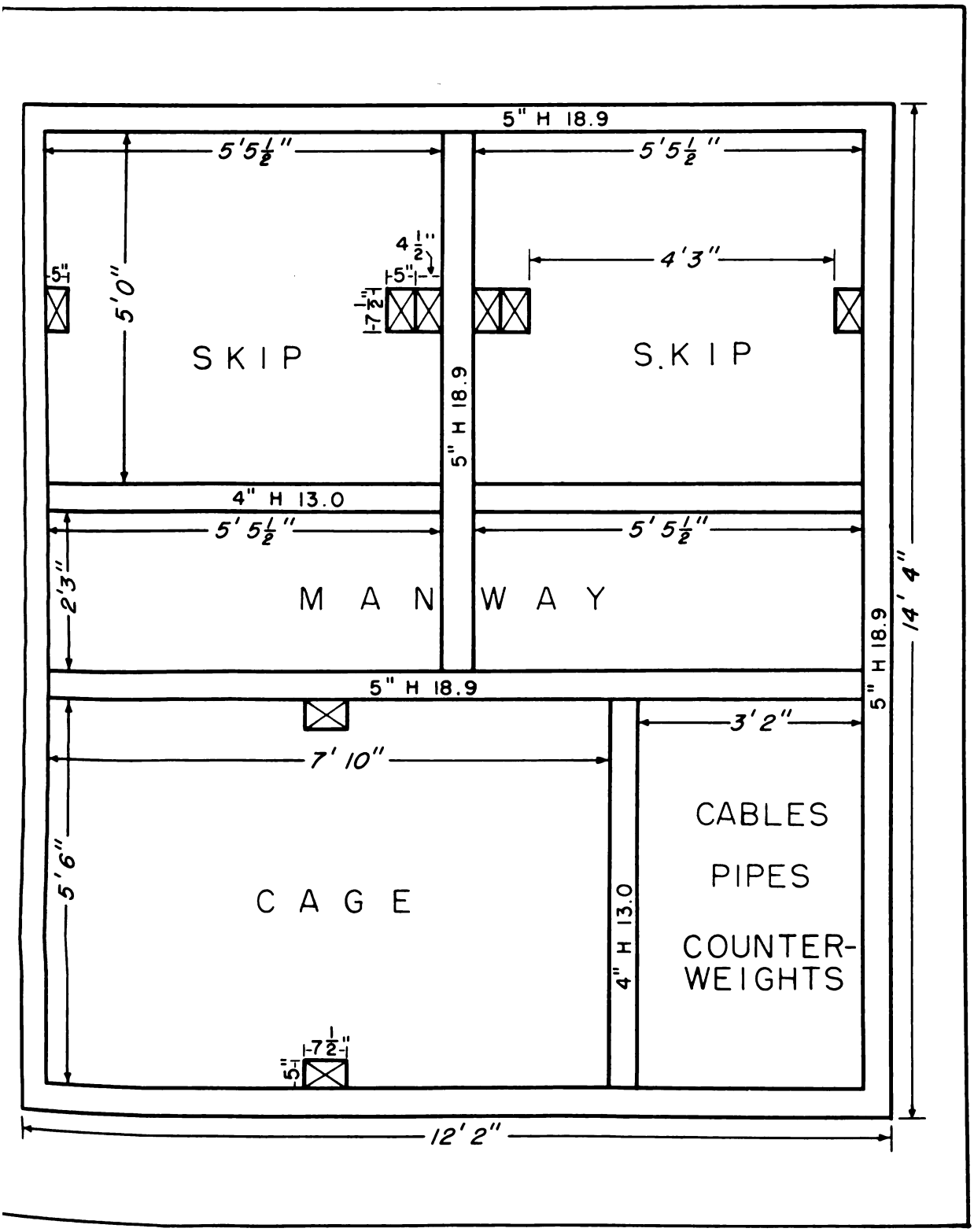

Figure 15. - Plan of compartments in B shaft.

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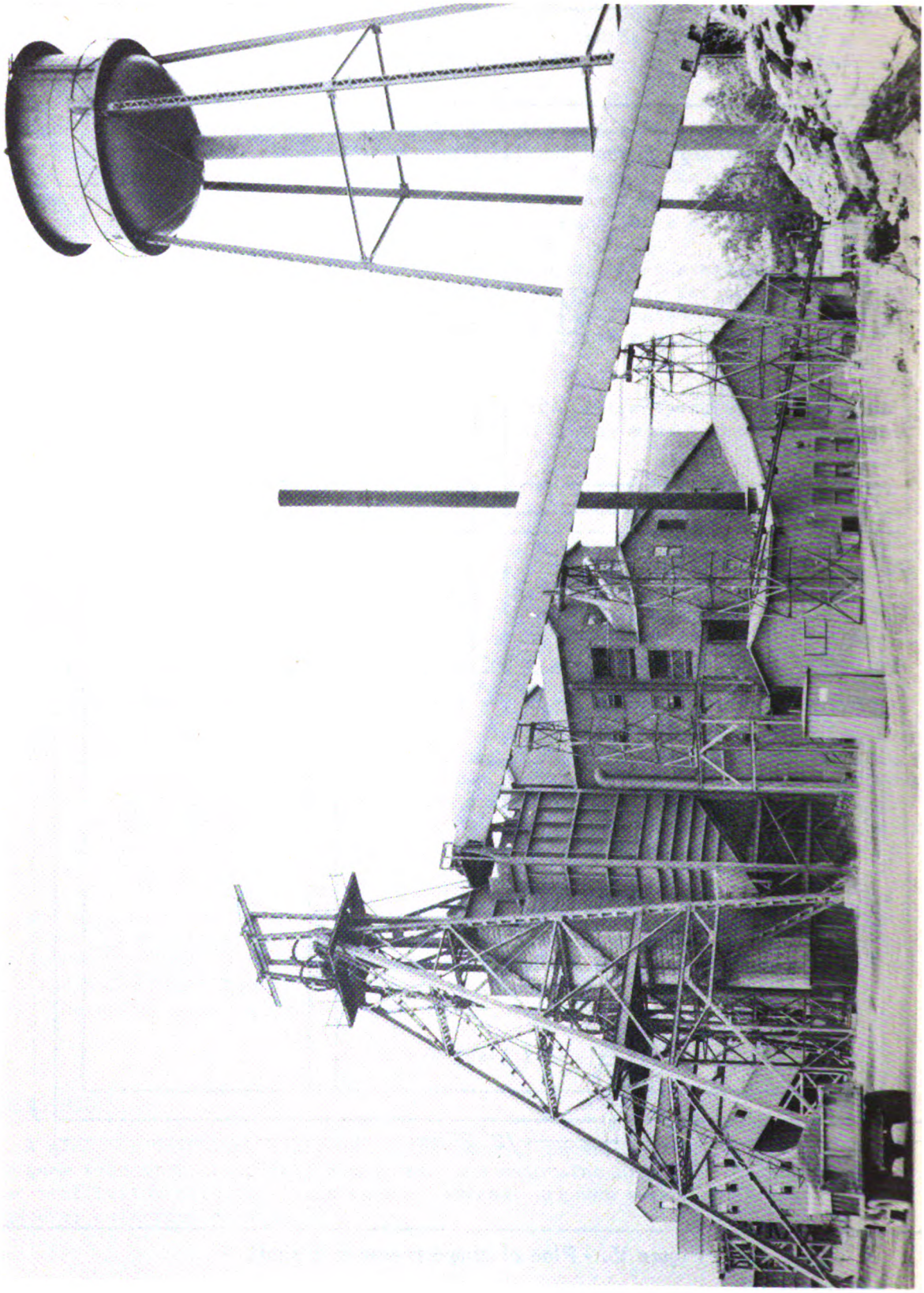

Figure 16. - Headframe and mill.

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Tractors equipped with bulldozer blades perform the following work, in addition to maintenance of roadways: (1) Moving chat from the bottom of one transfer raise to the top of another; (2) making final cleanup in the stopes after ore has been loaded in order that the drill jumbos may be moved and set up on a smooth floor; (3) building ramps with broken ore or waste to enable the jumbos to drill faces higher than their normal reach; (4) cleaning up fly rock before loading of ore begins; (5) stockpiling ore or waste; and (6) feeding the crusher-feeder pocket. The last-named operation is necessary when hoisting lags behind underground loading, hauling, and crushing to the extent that the storage pocket becomes filled. In such instances the trucks must dump their loads in front of the crusher-feeder pocket until hoisting has caught up with movement of ore underground.

Compressed Air

The compressor plant, which is installed in the hoistroom, consists of one 2,500-c.f.m., 2-stage, piston-type compressor driven by a 2,300-volt, 500-horsepower, synchronous electric motor; and a 2,213-c.f.m., 2-stage, piston-type compressor driven by a 2,300-volt, 400-horsepower, synchronous electric motor. The larger compressor is used on day shift and the last 5 hours of the night shift; the smaller one is used between shifts and at the beginning of the night shift. This alteration allows each unit to work in its best range of efficiency, permits the compressors and motors to cool, and provides for regular maintenance.

Compressed air is produced at a pressure of 115 p.s.i. and is delivered to the shaft in a 12-inch pipe, down the shaft in an 8-inch pipe, and from the shaft into the mine in 6-inch pipelines. The size of air line in the mine is further reduced successively to 4, 3, and 2 inches. Flanged couplings are used with the 12-inch pipes, whereas Victaulic couplings are used in the smaller pipelines.

Air is delivered to the drill jumbos from the branch air lines through 2-inch air hose. The small jumbo carries a small air receiver, from which 1-inch hoses deliver air to the drills. On the larger jumbo the air hose is connected to a 2-inch pipe that leads to a manifold from which the air passes through 1-inch lines to the drills. Air pressure at the drills is about 75 p.s.i.

Drill-Water Supply

Water for the rock drills is supplied from the plant's fresh-water system on the surface. Two-inch pipelines carry the water from a surface tank down the shaft and through the mine. Water is delivered to the drill jumbos through 1-inch hoses.

Maintenance and Repair

Maintenance and repair of equipment are done both on the surface and underground; nearly all light repair work is done in the mine (table 2).

The underground shop was cut in the footwall country rock near the station on the 763 level (fig. 17). The room is whitewashed and has a concrete floor. Most bench repairs are completed in this shop. Two welding machines are used underground; one is mounted on a light truck for use anywhere in the mine.

Most of the large underground equipment had to be cut apart on the surface and rewelded in the mine. The record times for cutting apart, lowering, and rebuilding machines were: 10 days for a shovel and 5 days for two 8-ton trucks.

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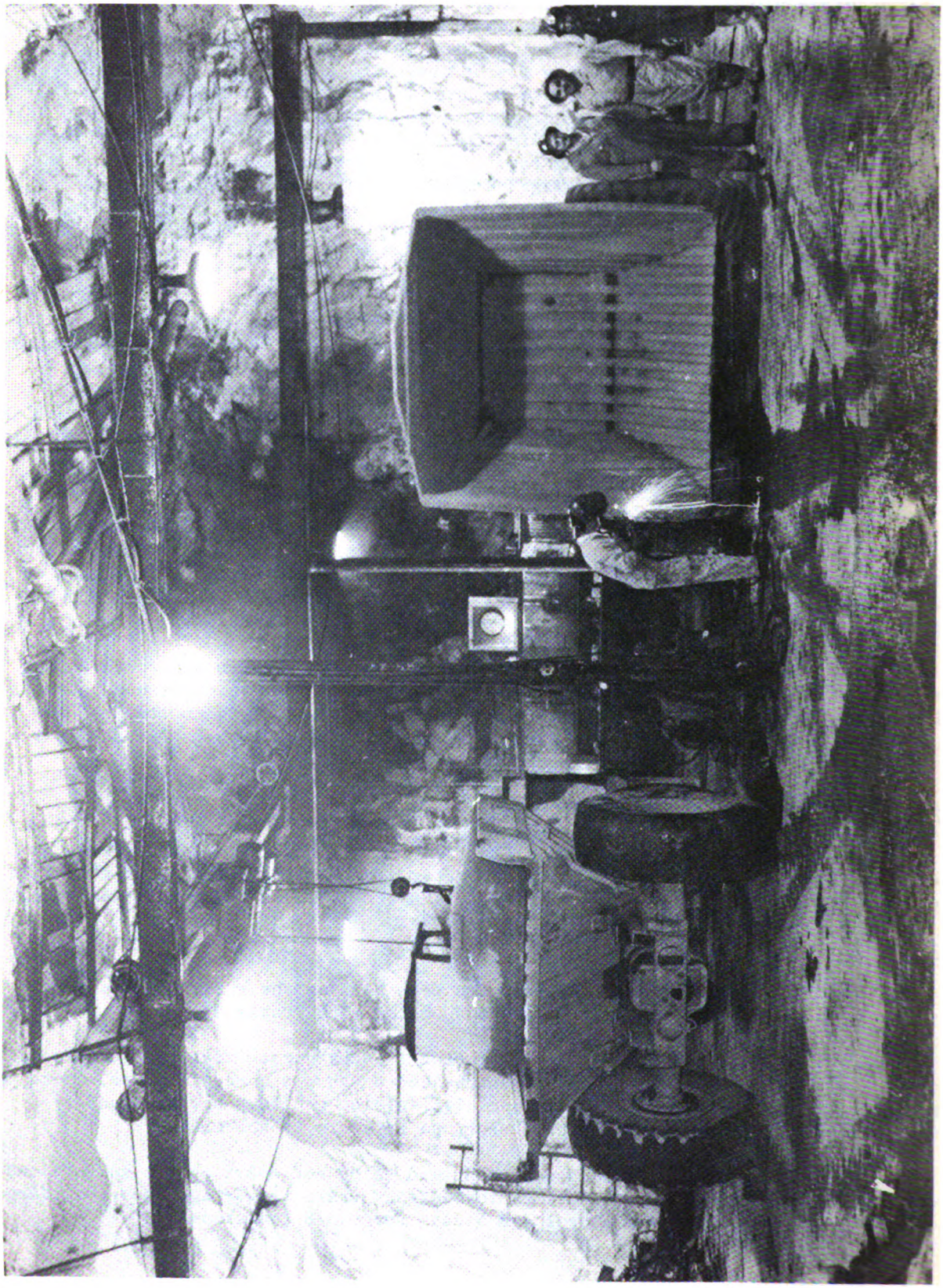

Figure 17. - Underground shop.

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TABLE 2. - Division of shop and maintenance labor

Surface	Underground
Building and repair of jumbo tracks.	Diamond-drill repairing and servicing.
Repair of the unit assemblies on shovels.	Pneumatic-drill repairing and servicing.
Fabrication of new parts for machines.	Maintenance of hydraulic and air mechanisms on drill jumbos.
Rebuilding rollers for tractor tracks.	Maintenance of all electric and rocker shovels, except motors.
Diesel-motor overhauls.	Maintenance of sashes and feed motors on drill jumbos.
Repair of ventilating fans.	Maintenance of crusher and pan feeder.
Repair of all electric motors.	Pump maintenance.
Regrinding bits.	All work on diesel motors except overhauls.
	General service and repair of trucks and crawler-mounted equipment, including lubrication and tire service.
	Drill-steel cutting, straightening, shanking, and threading.

Underground maintenance and repair work are done during both of the operating shifts; 1 to 3 mechanics and 1 or 2 welders are on duty during each shift.

Complete spare motors for trucks and loading machines are kept in stock, so that the equipment will not be idled while motors are being repaired or overhauled. If a disabled machine cannot be readily moved to the underground shop, a semiportable derrick, mounted on skids and equipped with a 5-ton chain block, is moved to the machine and used for changing motors and heavy subassemblies.

Storage and Handling of Explosives

Explosives are purchased in 25,000-pound lots and delivered to the mine by truck. The surface storage magazine is a small building on the side of Big Mountain, 3/8 mile north of B shaft and 150 feet higher in elevation (fig. 2). The magazine was built behind a projection of the hill, so that the plant is not directly exposed in case of accidental explosion at the magazine.

A supply of explosives is taken underground between shifts and stored in large wooden boxes on alternate working levels. The storage boxes are of heavy construction, hold 50 boxes of dynamite each, and are moved on skids, as mining advances, to protected positions near the working faces. Explosives are transported to the faces by the personnel car just before the drill holes are charged. Caps also are stored underground in heavy wooden boxes, at safe distances from the explosives.

Equipment, Power, and Supplies

Equipment

The major equipment used underground at Iron Mountain is listed in table 3.

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TABLE 3. - Underground equipment

Item	Type of power	Rated horsepower	Quantity
D-4 tractor with bulldozer blade	Diesel	45	1
D-8 tractor with bulldozer blade	do.	115	2
8-ton trucks (Dumpster)	do.	109	7
Hi-back trimmer (Chevrolet chassis)	do.	65	2
Hi-back trimmer (Euclid chassis)	do.	260	1
Model 104 loader (1-yard)	do.	45	2
Model 105 loader (1 1/2-yard)	do.	83	1
Model 105 loader (1 1/2-yard)	do.	125	1
Winch truck	do.	65	1
Drillmobile (Joy)	Air		3
Drill jumbo (Rogers)	Electric	20	4
Dipper shovel (3/4-yard)	do.	40	3
Jaw crusher (30- x 42")	do.	150	1
Crusher feeder (60-inch)	do.	10	1
60-inch ventilating fan	do.	50	1
66-inch ventilating fan	do.	40	1
36-inch ventilating fan	do.	40	3
Buffalo (Cg) ventilating fan	do.	15	1
TM-8 ventilating fan	do.	15	7
Pump, reciprocating (shaft)	do.	50	1
Pump, centrifugal	do.	40	1
Do.	do.	20	1
Do.	do.	15	1
Pump, deep-well	do.	20	1
Do.	do.	30	1

Power

Electric power is transmitted to the plant by the Arkansas-Missouri Power Co. at 33,000 volts and transformed to 2,300 volts at a 667-kv.-a. substation in the mine yard, using 3 single-phase transformers wired delta-delta. Power for the hoist and compressor and part of the power for the mill are transmitted at 2,300 volts. The rest of the power for the mill is transformed to 440 volts.

Power is transmitted underground at 2,300 volts to the 763 level, where a 2,300-volt line branches off to the crusher motor and a 3-phase, 500-kv.-a. transformer reduces the voltage for other electric motors to 440. Separate transformers are used for the 220-volt blasting circuit and the 110-volt lighting circuit. For lighting, 100-watt light globes are spaced irregularly along the levels.

Taps at the power company's transformers are set to supply 10 percent overvoltage. Ninety KVAR capacitors ride on the 440-volt lines at about two-thirds the distance to the load centers. Operating voltages are maintained at about their rated requirements by use of the capacitors and by setting the large compressor motors at a leading power factor of 0.90. The overall power factor is about 0.92 or 0.93. No feeder loops are used, and line losses are minimized by use of 2/0 wire. All underground machines powered by electricity have groundwires that lead from their frames back through the cables to the transformers.

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Supplies

All requisitions to the warehouse for supplies are signed by the foreman or shift boss with highest authority on his shift. Supplies are issued on day shift by the warehouseman and on the night shift by a watchman.

Replacement items are ordered by the warehouseman through requisitions to the chief clerk, who is also the purchasing agent. The inventory of parts and supplies is kept low. The expense of operating the warehouse is a very small part of the cost of mining.

Fuel oil is transferred from a tank on the surface through a 1-inch pipe, with pressure-reducing valve at the bottom, to an underground filling station on the 763 level. Consumption of fuel oil by diesel-powered equipment in 1955 averaged 0.07 gallon per long ton of ore mined.

PRODUCTION RATES AND PERCENTAGE OF EXTRACTION

Crude iron ore, containing 35 to 38 percent of iron, is mined at an average rate of about 2,000 long tons per day. The total output of ore from the mine in 1955, on a reduced operating schedule, was 345,424 wet long tons.

The mine is worked two shifts a day; both shifts begin at 7:00 o'clock and end at 3:30, with half an hour off for lunch. The bull gang and one oiler work an afternoon shift - from 12:00 noon until 8:30 p.m.

To maintain uniformity in the system of mining, some wall rock and dike rock are mined with the ore. Although some of the wall rock is clean waste, the greater part contains some ore. Waste and low-grade ore constitute about 5 percent and 10 to 15 percent, respectively, of the rock broken in stoping operations.

The areal extraction of ore on a mining level ranges from about 88 percent in the wider parts of the ore body to nearly 100 percent in the narrow parts. Between levels, where they are 36 feet apart vertically, mining extracts 24 feet of the ore in this interval, or 67 percent. Thus, room-and-pillar mining extracts 59 to 67 percent of the ore between levels. These percentages are increased considerably in some parts of the mine by extending the heights of rooms, on the hanging-wall side of the ore body, up to the hanging wall, even though these heights may be greater than the intervals between levels.

Parts of the horizontal pillars between levels are mined before a section of the mine is abandoned. These level pillars are removed in blocks 35 feet wide and 90 feet long, leaving transverse pillars 20 feet wide and 110 feet between centers. This method of pillar recovery raises the extraction of ore between levels to more than 75 percent.

VENTILATION

Fresh air is drawn from the surface into the mine workings in the Main ore body through A shaft, which extends to the 837 level (fig. 18). This shaft and part of the 837 level were opened during the period of underground mining from 1921 to 1930. All connections between the shaft and stopes in the conglomerate ore body were sealed.

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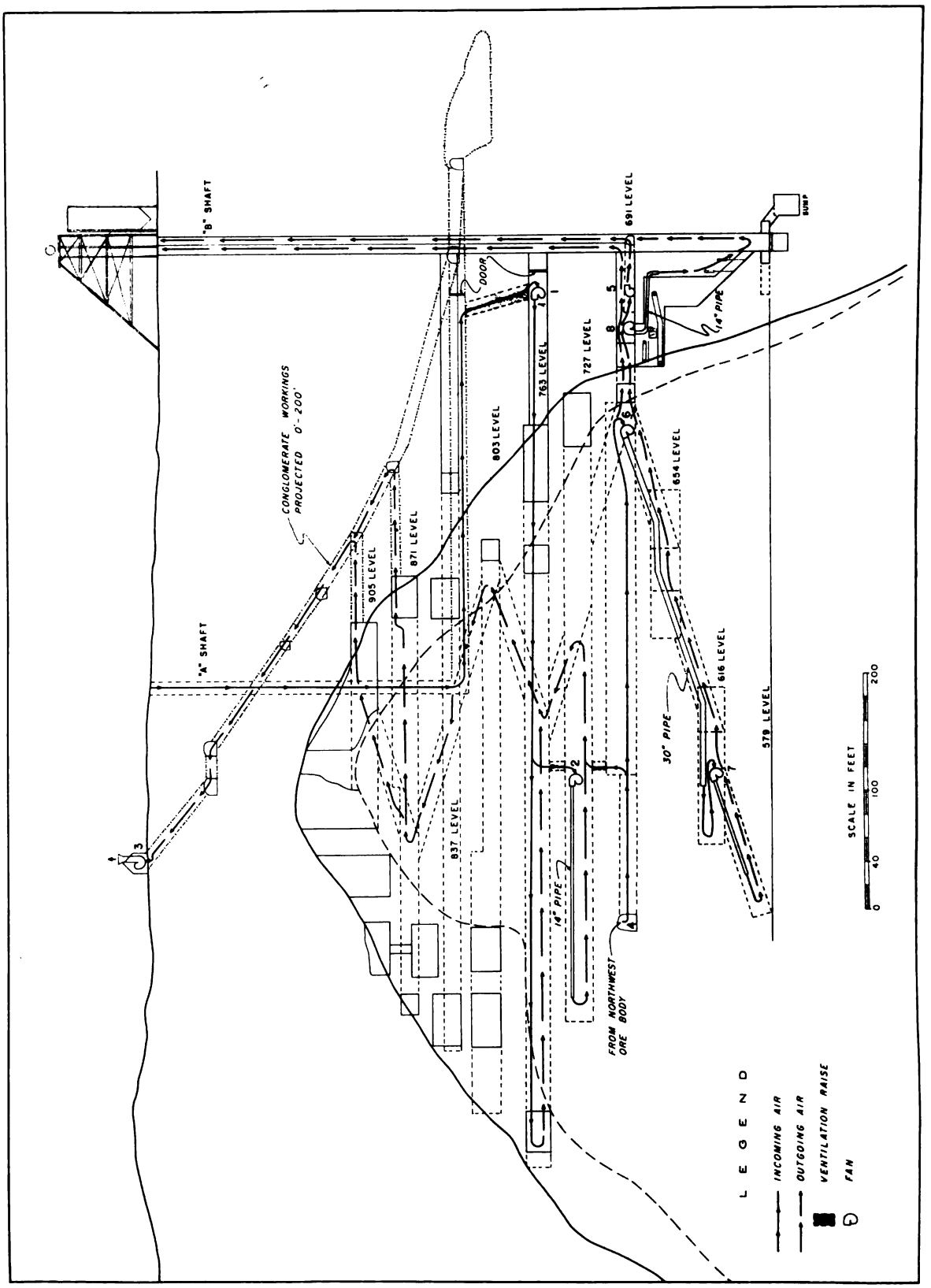

Figure 18. - Schematic diagram of ventilation system.

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The ventilating air is drawn by a 60-inch fan (1, fig. 18) from the 837 level through a 6- by 6-foot raise to the 763 level at a rate of 70,000 c.f.m. against a 2-inch (water-gage) pressure. The fan is belt driven by a 50-horsepower electric motor. Part of the air is drawn down to the 727 level on the north side of the ore body by a 36-inch, 40-horsepower fan (2, fig. 18); the rest ventilates all of the 763 level, then passes up through the inclines and ventilates the upper workings. Connections to the conglomerate workings on the 837 and higher levels allows the air to pass into these abandoned workings and out to the surface through two inclines. A Buffalo fan (3, fig. 18), driven by a 15-horsepower electric motor, assists movement of air to the surface by exhausting air through 1 of the inclines at a rate of 30,000 c.f.m.

Fresh air reaches the workings in the Northwest ore body through a 6- by 6-foot raise, opened from the 765 level to the surface. A 66-inch ventilating fan, mounted at the top of the raise and driven by a 40-horsepower electric motor, forces air into the mine at a rate of 70,000 c.f.m. against a 2-inch (water-gage) pressure. The shrinkage stope in the upper part of the ore body and the 803 level are ventilated directly from connections to the raise. The crosscut from the Main ore body on the 803 level is sealed off by a door, and movement of air through the levels is controlled by curtains to ensure effective ventilation of all the workings. After circulating through the workings in the Northwest ore body, the ventilating air passes through the 691 level crosscut to the Main ore body (4, fig. 18). Thence a split on the north side of the 691 level directs a small part of the air up through a raise to the 727 level, where it mixes with the air from A shaft. The rest is drawn toward the shaft station on the 691 level at B shaft by a 36-inch fan, driven by a 40-horsepower electric motor (5, fig. 18). A similar 36-inch fan (6, fig. 18) picks up most of the air stream on the 691 level and forces the air to the lowest working level through a 30-inch ventilation pipe. Thence the air returns by way of the inclines to the exhaust fan at the 691 shaft station and is upcast through the skip side of B shaft, which is separately compartmented all the way to the collar. The manway and cage compartments of B shaft are also upcast, but with natural draft. No flow of air enters the shaft at any level above the 691.

Blind working places on all levels are ventilated by Coppus TM-8 fans, which draw air from the nearest main air circuit and force it through 14-inch pipes to the faces (7, fig. 18). Each of these fans, driven by 15-horsepower electric motors, delivers the ventilating air at rates of 5,000 to 7,500 c.f.m.

Ventilating air reaches the crusher room and 579 shaft station through a 14-inch pipe from a TM-8 fan on the 691 level (8, fig. 18).

Measurements of air flows are made with anemometer traverses through the mine workings. In the large openings, where the movement of air is slow, the average velocity is determined by timing the rate of flow of smoke generated by smoke bombs.

The exhausts of all diesel engines are equipped with scrubbers, which consist, with one exception, of tanks containing solutions of a basic carbonate in water. The 125-horsepower loader is equipped with an oxy-catalyst scrubber. Intermittent checks of the areas most subject to air pollution, using SAFE CO testing tubes and aspirators, have never revealed a concentration of carbon monoxide that would be unsafe for 8-hour exposure. Loader operators are instructed to stop work at any time they believe that the air is poor.

The ventilation system, in addition to supplying 100 c.f.m. of air for each man working underground, provides circulation of air equivalent to 71.14 c.f.m. for

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each rated brake-horsepower of the underground equipment. Allowing for the use factors of these machines, over 125 c.f.m. of the air is available per brake-horsepower.

Dust counts are made at approximately 3-month intervals, using a konimeter with an alcohol trap. Wet drilling eliminates dust at the face, and a rapidly settling fog from scrubbers on the diesel trucks apparently prevents the formation of dust in the roadways.

Air temperatures underground range from about 65° to 70° F.

MINE DRAINAGE

Water is pumped from the mine at a rate of about 70 to 80 gallons per minute. The source of about half of this water is the feed water for pneumatic and diamond drills. Primary sources are water-bearing fissures that drain into the lowest levels; fissures tapped by the diamond drills; and water that seeps into the shaft near the surface. The water tapped by diamond drills is under fairly high pressures at first, but the fissures usually run dry within 3 to 6 weeks.

The water that drains into the mine below the 616 level is lifted from temporary sumps by portable air-driven pumps, with 2-inch discharges, to a sump on the 616 level. A centrifugal pump, driven by a 15-horsepower electric motor, lifts the water from there to a gathering sump on the 691 level. This sump also receives, by natural flow, all the drainage water from the workings in the Northwest ore body and levels 691, 727, and the south half of the 763 level in the Main ore body. A 40-horsepower centrifugal pump on the 691 level pumps water from the gathering sump to the 763 level, thence out through a drift into the abandoned conglomerate workings which serves as a sump. This sump, which has 2 entries from the 763 level, has a capacity of about 90,000 gallons.

A sump at the bottom of B shaft collects the water that drains into the shaft from the ore-storage pocket, the north side of 763 level, and from near the surface. Water is lifted by a 50-horsepower reciprocating pump from this sump to a pipe on the 837 level, through which it drains by gravity into the sump in the conglomerate workings. The final stage in unwatering the mine is removal of water from this sump to the surface by a 30-horsepower, deep-well pump, operating through a connecting drill hole.

The pumping system is so arranged that, by means of control valves, water can be diverted from its regular courses above the 691 level and pumped directly to the surface through the shaft pipelines.

All discharge pipes in the shaft are 6 inches in diameter. Victaulic couplings are used in the pipe columns.

Water pumped from the mine enters the surface drainage system. This surface water is trapped by the dike that encloses the tailing pond and is available for use in the mill.

MILLING OPERATIONS

Crushed ore is hoisted from the mine and dumped into the mill-feed bin at a maximum rate of 2,400 long tons a day. The mill is operated 16 hours a day, 5 days a week. The crew consists of the following personnel: A mill superintendent, a foreman and 14 men on shift 1, a maintenance foreman and 5 men on shift 2, and a foreman and 13 men on shift 3.

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The duties of shifts 1 and 3 are strictly operating. The crew on shift 2 drains the water from the plant in freezing weather, performs the required maintenance work on equipment, and refills the plant with water, if drained, preparatory to resuming operations on shift 3.

Figure 16 is an outside view of the mill building and headframe of the hoisting shaft. Figure 19 is a detailed flowsheet of the beneficiating plant.

Crushing

Primary crushing is done underground in a 30- by 42-inch Pioneer jaw crusher set at 5 inches; the crushed ore is then hoisted to a 500-ton receiving bin at the head of the mill. Ore from this bin passes over a 5- by 6-foot Allis-Chalmers screen with 2-inch openings. The plus-2-inch ore is crushed in two 10- by 36-inch Kue-Ken jaw crushers and after combining with the minus 2-inch ore from the screen is conveyed to two 5- by 10-foot double-deck Ty-rock screens, with 1 1/4-inch openings in the upper screen and 1/2-inch in the lower. The plus-1/2-inch ore is crushed in two 4-foot Symons cone crushers in closed circuit with a Ty-rock screen.

The minus-1/2-inch ore from both sets of screens is weighed by a Merrick weightometer, sampled, and conveyed to a second conveyor, where it joins the reground and dewatered minus-8-mesh jig middling and is conveyed to 1 of 2 jig feed bins. The conveyor system is so arranged that, when the first bin is full, a swing-type conveyor diverts the material to the second bin. Each of the bins is equipped with four roll-type feeders for feeding the ore to four 3-cell Pan American jigs.

Jigging

Seven 3-cell jig units are in continuous operation, and one standby unit is used as needed. The first two cells of each jig unit produce a coarse concentrate and a fine (hutch) concentrate; the third cell produces coarse middling and fine middling. Coarse tailing is produced at the overflow of the third cell. Concentrates are dewatered in two 36-inch by 21-foot-6-inch Wemco classifiers, sampled automatically and conveyed by a system of 2 conveyors to a 100-ton concentrate storage bin (fig. 20). The tailing is dewatered in a 60-inch by 31-foot-9-inch Wemco classifier, sampled automatically, and delivered by two conveyors to a 60-ton coarse-tailing bin (fig. 20). The jig middlings are dewatered in a 48-inch by 21-foot-6-inch Akins classifier, ground to minus-8-mesh in a 7- by 12-foot Hardinge rod mill, and dewatered in a 36-inch by 19-foot-3-inch Wemco classifier located to obtain a gravity flow of the products. The dewatered minus-8-mesh middling joins the crushed minus-1/2-inch ore, as noted above, and is delivered to the jig feed bins.

The jig cells have effective screen areas of 42 by 42 inches, with slotted 3/16- by 3/4-inch openings. The stroke is 1 5/8 inches, at a rate of 160 strokes per minute. Each of the 3-cell units requires 500 gallons of water per minute, which is supplied from a 10,000-gallon constant-head tank.

Tabling

Overflows from the dewatering classifiers are pumped to a 60-foot Hardinge thickener, except that from the reground jig-middling classifier, which flows by gravity. The thickener underflow is moved by two 4-inch Dorrco diaphragm pumps to a 3-inch Pettibone-Mulliken pump that discharges into a 6-way table-feed distributor.

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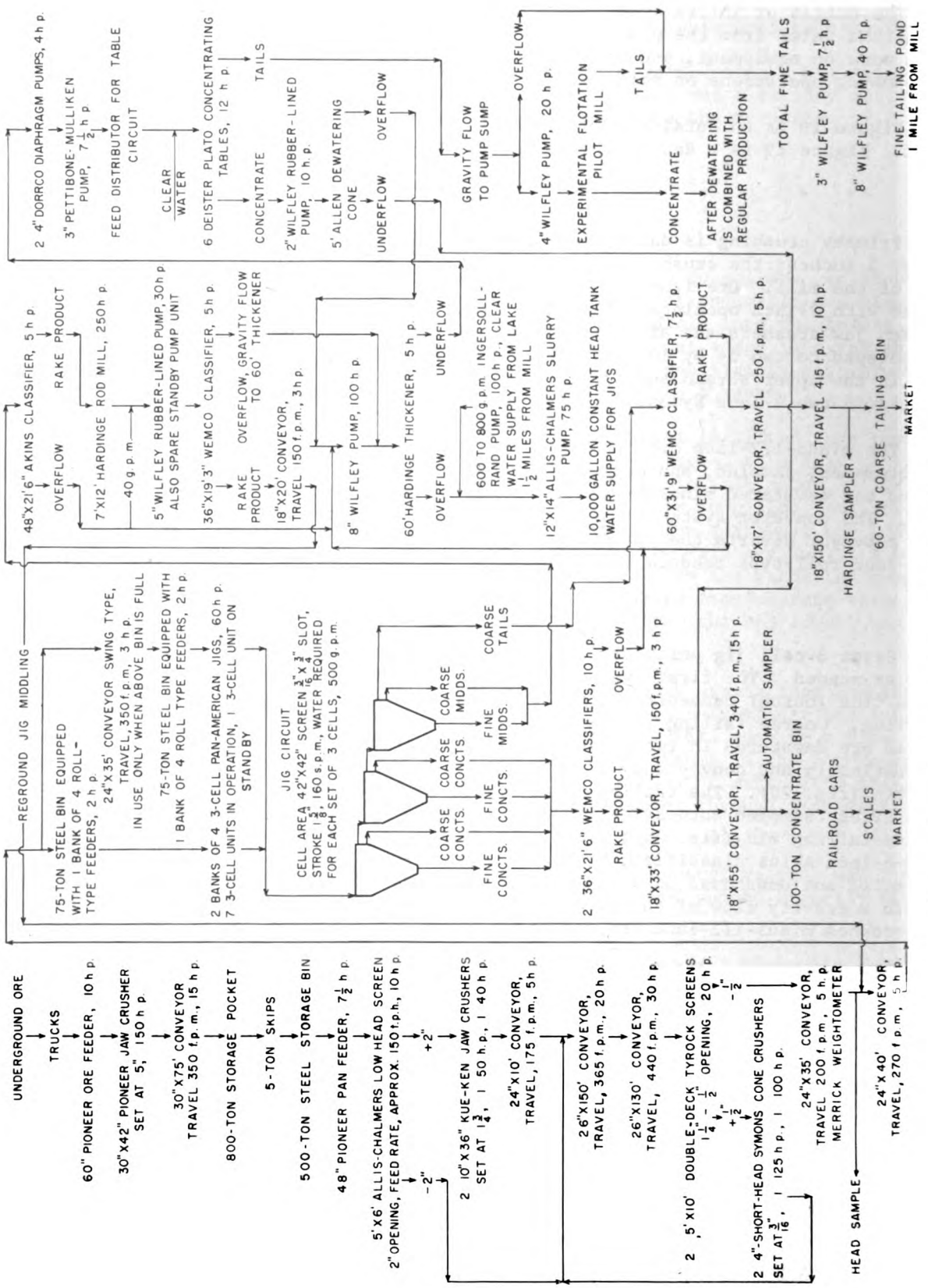
UNDERGROUND ORE
TRUCKS
60" PIONEER ORE FEEDER, 10 h p
30"X42" PIONEER JAW CRUSHER SET AT 5", 150 h p
30"X75' CONVEYOR TRAVEL 350 f.p.m., 15 h p
800-TON STORAGE POCKET
5-TON SKIPS
500-TON STEEL STORAGE BIN
48" PIONEER PAN FEEDER, 7½ h p
5'X6' ALLIS-CHALMERS LOW HEAD SCREEN 2" OPENING, FEED RATE, APPROX. 150 t.p.h., 10 h p
-2"
+2"
2 10"X36" KUE-KEN JAW CRUSHERS SET AT 1¾", 1 50 h.p., 1 40 h p
24"X10' CONVEYOR, TRAVEL, 175 f.p.m., 5h p.
26"X150' CONVEYOR, TRAVEL, 365 f.p.m., 20 h p.
26"X130' CONVEYOR, TRAVEL, 440 f.p.m., 30 h p.
2 5'X10' DOUBLE-DECK TYROCK SCREENS 1¼" - ½" OPENING, 20 h p.
1" - ½"
+1" +½"
2 4"-SHORT-HEAD SYMONS CONE CRUSHERS SET AT 3/16", 1 125 h p., 1 100 h p.
24"X35' CONVEYOR, TRAVEL 200 f.p.m., 5 h.p. MERRICK WEIGHTOMETER
HEAD SAMPLE
24"X40' CONVEYOR, TRAVEL, 270 f p m., 5 h p.
REGROUND JIG MIDDLING
75-TON STEEL BIN EQUIPPED WITH 1 BANK OF 4 ROLL-TYPE FEEDERS, 2 h p
24"X35' CONVEYOR SWING TYPE, TRAVEL, 350 f.p.m., 3 h p, IN USE ONLY WHEN ABOVE BIN IS FULL
75-TON STEEL BIN EQUIPPED WITH 1 BANK OF 4 ROLL TYPE FEEDERS, 2 h p.
2 BANKS OF 4 3-CELL PAN-AMERICAN JIGS, 60 h p.
7 3-CELL UNITS IN OPERATION, 1 3-CELL UNIT ON STANDBY
JIG CIRCUIT
CELL AREA 42"X42" SCREEN 5/16"X3/4" SLOT, STROKE 1 5/8", 160 s.p.m., WATER REQUIRED FOR EACH SET OF 3 CELLS, 500 g.p.m.
COARSE CONCTS.
FINE CONCTS.
COARSE CONCTS.
FINE CONCTS.
COARSE MIDDS.
FINE MIDDS.
COARSE TAILS
2 36"X21'6" WEMCO CLASSIFIERS, 10 h.p.
RAKE PRODUCT
OVERFLOW
18"X33' CONVEYOR, TRAVEL, 150 f.p.m., 3 h p
48"X21'6" AKINS CLASSIFIER, 5 h p.
OVERFLOW
RAKE PRODUCT
7'X12' HARDINGE ROD MILL, 250 h p
40 g p m
5" WILFLEY RUBBER-LINED PUMP, 30 h p ALSO SPARE STANDBY PUMP UNIT
36"X19'3" WEMCO CLASSIFIER, 5 h p
RAKE PRODUCT
OVERFLOW, GRAVITY FLOW TO 60' THICKENER
18"X20' CONVEYOR, TRAVEL 150 f.p.m., 3 h p
8" WILFLEY PUMP, 100 h p
60' HARDINGE THICKENER, 5 h p.
OVERFLOW
UNDERFLOW
600 TO 800 g p m INGERSOLL-RAND PUMP, 100 h p., CLEAR WATER SUPPLY FROM LAKE 1½ MILES FROM MILL
12"X14" ALLIS-CHALMERS SLURRY PUMP, 75 h p
10,000 GALLON CONSTANT HEAD TANK WATER SUPPLY FOR JIGS
60"X31'9" WEMCO CLASSIFIER, 7½ h p.
OVERFLOW
RAKE PRODUCT
18"X17' CONVEYOR, TRAVEL 250 f.p.m., 5 h p.
18"X150' CONVEYOR, TRAVEL 415 f.p.m., 10 h p.
HARDINGE SAMPLER
60-TON COARSE TAILING BIN
MARKET
18"X155' CONVEYOR, TRAVEL, 340 f.p.m., 15 h p.
AUTOMATIC SAMPLER
100-TON CONCENTRATE BIN
RAILROAD CARS
SCALES
MARKET
2 4" DORRCO DIAPHRAGM PUMPS, 4 h p.
3" PETTIBONE-MULLIKEN PUMP, 7½ h p
FEED DISTRIBUTOR FOR TABLE CIRCUIT
CLEAR WATER
6 DEISTER PLATO CONCENTRATING TABLES, 12 h p
CONCENTRATE
TAILS
2" WILFLEY RUBBER-LINED PUMP, 10 h. p.
5' ALLEN DEWATERING CONE
UNDERFLOW
OVERFLOW
GRAVITY FLOW TO PUMP SUMP
OVERFLOW
4" WILFLEY PUMP, 20 h p.
EXPERIMENTAL FLOTATION PILOT MILL
TAILS
CONCENTRATE
AFTER DEWATERING IS COMBINED WITH REGULAR PRODUCTION
TOTAL FINE TAILS
3" WILFLEY PUMP, 7½ h p
8" WILFLEY PUMP, 40 h p
FINE TAILING POND
1 MILE FROM MILL

Figure 19. - Flowsheet of Ozark Ore Co. mill—1956.

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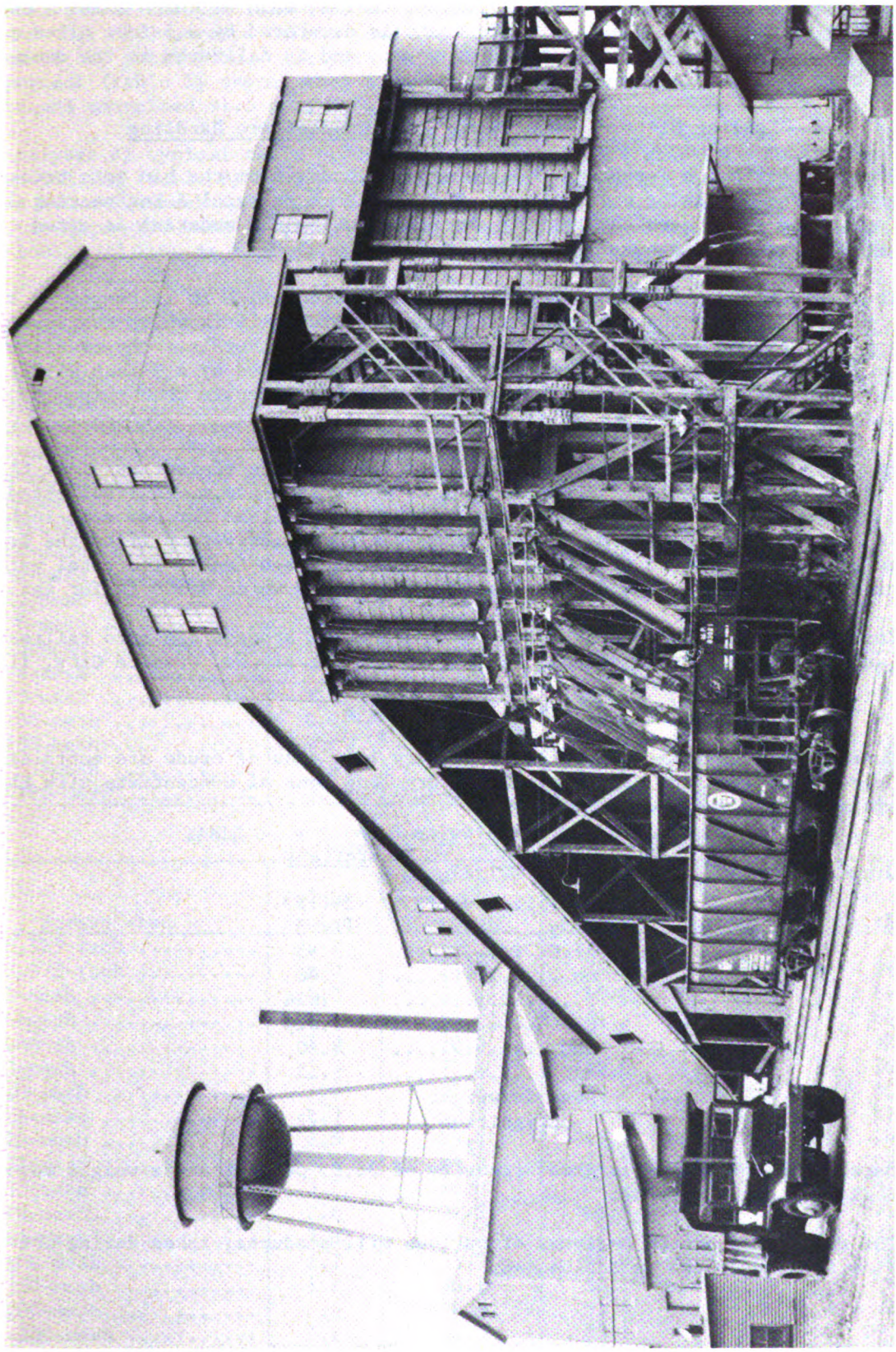

Figure 20. - Storage bins and loading chutes for concentrate and coarse tailing.

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The table circuit consists of six Deister tables, each of which makes a concentrate and a tailing. The combined concentrate is dewatered by a 5-foot Allen cone, flows by gravity to the jig concentrate conveyor, and is delivered to the concentrate storage bin.

Tailing Disposal, Mill Water, and Concentrate Handling

The jig tailing, a merchantable product, is loaded from the bin into trucks for delivery to a stockpile or to a jobber. The Trap Rock Material & Engineering Co. has a screening plant near the tailing stockpile, where the material is sized to meet market specifications.

The table tailing flows by gravity to a sump, from which it is pumped by a 4-inch Wilfley pump to the experimental flotation pilot mill in which testwork is underway to separate hematite from the siliceous gangue minerals. The overflow from the sump and the tailing from the flotation plant are pumped by a 3-inch Wilfley pump to a general sump. The material collected in this sump is then pumped to the fine-tailing pond by an 8-inch Wilfley pump.

The main supply of mill water is the overflow from the 60-foot Hardinge thickener. Additional mill water is supplied by a 600- to 800-g.p.m. Ingersoll-Rand centrifugal pump, which delivers the water from a nearby lake through a 12-inch pipeline to the mill. A 12- by 14-inch Allis-Chalmers slurry pump lifts the fresh and recirculating water to the 10,000-gallon constant-head tank. The total water requirement for milling is 4,300 gallons per minute, of which 3,500 is for the jigs.

Concentrate is drawn from the 100-ton concentrate storage bin into railroad cars, weighed, sampled, and shipped to Granite City Steel Co., Granite City, Ill.

Metallurgical Data

During 1955 the mill treated 339,690.4 dry long tons of crude ore containing 38.18 percent of iron and produced 208,007 dry long tons of concentrate with the following weighted average analysis:

Component	Percent
Fe	54.15
SiO_2	11.55
Al_2O_3	2.93
Mn	.40
P	.014
S	.014
CaO	4.50
MgO	1.12
Loss in weight on ignition	1.72

Data indicated a metallurgical recovery of 86.85 percent and a weight recovery (dry basis) of 61.23 percent.

The results of screen analyses of various mill products, taken during one operating day, are shown in tables 4-8.

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Analysis of the jig feed (table 4) showed that it contained 33.9 percent of iron and that 92.0 percent of the feed was plus-35-mesh in size and contained 92.7 percent of the total iron. Analysis of a jig concentrate with an iron content of 53.1 percent (table 5) showed that 90 percent of the concentrate was plus-35-mesh in size and contained 91.5 percent of the iron.

Analyses of typical table products, including feed (table 6), concentrate (table 7), and tailing (table 8) showed that about three-fourths of the table feed and tailing was minus-200-mesh in particle size, whereas only about 47 percent of the concentrate was minus-200-mesh in size. These screen analyses show, therefore, that the major losses of iron in tabling operations are in material finer than 200-mesh.

TABLE 4. - Screen analysis of jig feed

Screen size	Weight, percent	Cumulative weight, percent	Analysis, percent Fe	Percent of total Fe	Cumulative percent total Fe
Plus-0.525-inch	-	-	-	-	-
Plus-0.375-inch	18.0	18.0	36.9	19.6	19.6
Plus-3-mesh	25.2	43.2	36.1	26.8	46.4
Plus-4-mesh	16.5	59.7	32.6	15.9	62.3
Plus-6-mesh	10.2	69.9	33.0	9.9	72.2
Plus-8-mesh	6.0	75.9	32.3	5.7	77.9
Plus-10-mesh	6.0	81.9	32.7	5.8	83.7
Plus-14-mesh	3.6	85.5	31.0	3.3	87.0
Plus-20-mesh	2.8	88.3	30.3	2.5	89.5
Plus-28-mesh	2.1	90.4	29.8	1.8	91.3
Plus-35-mesh	1.6	92.0	30.0	1.4	92.7
Plus-48-mesh	1.2	93.2	30.2	1.1	93.8
Plus-65-mesh	1.0	94.2	31.4	.9	94.7
Plus-100-mesh	2.2	96.4	30.8	2.0	96.7
Plus-150-mesh	1.0	97.4	31.2	.9	97.6
Plus-200-mesh	.6	98.0	30.2	.5	98.1
Minus-200-mesh	2.0	100.0	31.7	1.9	100.0

TABLE 5. - Screen analysis of jig concentrate

Screen size	Weight, percent	Cumulative weight, percent	Analysis, percent Fe	Percent of total Fe	Cumulative percent total Fe
Plus-0.525-inch	-	-	-	-	-
Plus-0.375-inch	28.0	28.0	55.0	29.0	29.0
Plus-3-mesh	24.3	52.3	55.0	25.2	54.2
Plus-4-mesh	12.3	64.6	54.3	12.6	66.8
Plus-6-mesh	5.9	70.5	55.3	6.1	72.9
Plus-8-mesh	3.7	74.2	56.0	3.9	76.8
Plus-10-mesh	3.6	77.8	56.2	3.8	80.6
Plus-14-mesh	2.7	80.5	53.7	2.7	83.3
Plus-20-mesh	2.8	83.3	49.9	2.7	86.0
Plus-28-mesh	3.5	86.8	45.1	3.0	89.0
Plus-35-mesh	3.2	90.0	41.4	2.5	91.5
Plus-48-mesh	2.8	92.8	40.3	2.1	93.6
Plus-65-mesh	2.4	95.2	42.4	1.9	95.5
Plus-100-mesh	1.7	96.9	44.0	1.4	96.9
Plus-150-mesh	1.2	98.1	50.1	1.1	98.0
Plus-200-mesh	.8	98.9	51.8	.8	98.8
Minus-200-mesh	1.1	100.0	55.7	1.2	100.0
Total	100.0	100.0	53.1	100.0	100.0

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TABLE 6. - Screen analysis of table feed

Screen size	Weight, percent	Cumulative weight, percent	Analysis, percent Fe	Percent of total Fe	Cumulative percent, total Fe
Plus-35-mesh	0.1	0.1	20.1	0.1	0.1
Plus-48-mesh	.6	.7	12.3	.2	.3
Plus-65-mesh	2.0	2.7	20.0	1.5	1.8
Plus-100-mesh	5.0	7.7	16.0	3.0	4.8
Plus-150-mesh	9.4	17.1	21.6	7.6	12.4
Plus-200-mesh	9.1	26.2	25.6	8.7	21.1
Minus-200-mesh	73.8	100.0	28.6	78.9	100.0
Total	100.0	100.0	26.8	100.0	100.0

TABLE 7. - Screen analysis of table concentrate

Screen size	Weight, percent	Cumulative weight, percent	Analysis, percent Fe	Percent of total Fe	Cumulative percent, total Fe
Plus-35-mesh	1.0	1.0	29.7	0.6	0.6
Plus-48-mesh	3.8	4.8	48.8	3.7	4.3
Plus-65-mesh	5.2	10.0	48.3	5.0	9.3
Plus-100-mesh	7.1	17.1	45.6	6.4	15.7
Plus-150-mesh	16.6	33.7	46.1	15.2	30.9
Plus-200-mesh	19.4	53.1	48.8	18.8	49.7
Minus-200-mesh	46.9	100.0	53.8	50.3	100.0
Total	100.0	100.0	50.3	100.0	100.0

TABLE 8. - Screen analysis of table tailing

Screen size	Weight percent	Cumulative weight, percent	Analysis, percent Fe	Percent of total Fe	Cumulative percent, total Fe
Plus-100-mesh	12.4	12.4	7.3	4.0	4.0
Plus-150-mesh	7.6	20.0	13.4	4.5	8.5
Plus-200-mesh	4.9	24.9	17.6	3.9	12.4
Minus-200-mesh	75.1	100.0	26.3	87.6	100.0
Total	100.0	100.0	22.5	100.0	100.0

WAGE AND INCENTIVE PAY SYSTEM; INSURANCE

Wage rates at the Iron Mountain mine are the same as those at all major iron mines, being controlled by a master contract with United Steelworkers of America, CIO. The labor supply is adequate, as wage rates are higher than those of other local industries. Most of the workmen come from towns, villages, and farms within a 25-mile radius of the mine.

Certain types of work are usually performed under an incentive system. "Contract work", as it is called, is done where footage is the most important objective, or when a speedup in production is necessary. Most inclines, all raises, and some small drifts are driven on contract. Although the output per man-shift is much higher on a production contract than on a straight wage basis, contract prices are set too high for the company to realize a financial benefit. In all instances the workmen are guaranteed their normal daily wages. Company work done by a contract worker is paid for at the base rate for his job classification.

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The workmen on day and night shifts rotate their shifts each week. The pay differentials are 6 cents an hour for work on the afternoon shift and 9 cents an hour for the night shift.

Recognition for service is made by giving annual dinners, service pins, layoff protection, and retirement pay. Retirement is possible at age 65, or sooner if a worker is incapacitated after 15 years of service. The amount of retirement pay is based on the number of years served and the average earnings for the last 10 years of employment. Retirement is not normally compulsory but may be required of an employee if he becomes unable to fulfill the requirements of his job.

Each workman contributed $8.55 a month in 1955 toward the payment of premiums on health, accident, life, and compensation insurance. The company paid the rest of the costs of insurance, which included Blue Cross, Blue Shield, $3,000 of life insurance, and a payment of $40 a week up to 26 weeks to those disabled because of sickness. Disability from an accident is compensated for periods up to 20 weeks; compensation beyond that period is determined by the nature and degree of disability.

STAFF ORGANIZATION

The company staff is organized into separate departments, each with a department head, for the following classifications of work: Geology, engineering, mine operations, mechanical, electrical, chemistry and sampling, mill operations, and mine office. Each department head reports directly to the superintendent. Requests for work orders are prepared by department heads and submitted to the departments concerned with the work. The mine office staff is headed by a chief clerk, who supervises the statistical, accounting, payroll, and warehouse subdepartments.

SAFETY, FIRST-AID TRAINING, AND FIRE PREVENTION

The efficient planning and execution of operations, the maintenance of sound walls and backs in the mine, the careful use of well-chosen equipment, and safe working practices have resulted in a good safety record at Iron Mountain. The record in 1955 is very favorable compared with the average for previous years, as shown in table 9. This average includes the records for the period of open-pit mining.

TABLE 9. - Lost-time injury rates

Period	Frequency rate[1/]	Severity rate[2/]	Man-hours worked
1945-55 (average).	38.10	5.230	288,717
1955	16.62	.270	240,656

1/ Lost-time injuries per million man-hours.
2/ Man-shifts lost per thousand man-hours.

Every 3 months a small cash prize is awarded to each man who has a no-lost-time record for the period.

Walls and backs in the mine are inspected daily. Safety meetings and general safety inspections are held every 8 weeks by a committee consisting of the superintendent, mine captain, mill superintendent, and a union representative from each of the mine, mill, and surface crews. Suggestions or recommendations are made by the committee and submitted to the general superintendent for consideration. On the Monday following a general inspection a meeting is held, on company time, for all company employees who are working on the day shift at that time. Recommendations

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of the safety committee, the actions taken, and other safety subjects are discussed. In addition, use of a suggestion box is encouraged.

The hoisting ropes are inspected monthly by the master mechanic. The broken wires per lay are counted, the diameter of the rope measured, and a drop test is made to check functioning of the cage's safety dogs. At times, 10 feet of the rope is cut off at the end next to cage or skip, where vibration causes a much higher rate of individual wire breakage than elsewhere. The wire ropes are lubricated by an automatic drip oiler at the headsheave.

The use of safety clothing, such as hard-toed shoes and hard hats, is required. Trimmermen and shopmen wear goggles, and respirators are furnished to the trimmermen when working from catwalks.

First-aid courses have been conducted three times since 1949, either by the Bureau of Mines or the Red Cross. An average of 2 supervisors and 15 workmen has been instructed in first-aid methods during each course. Training was also given in use of the Chemox apparatus, duplicate sets of which are kept ready for use.

The absence of timber in the mine and fireproof construction in the shaft minimize the fire hazard. Soda fire extinguishers are placed on each of the large underground machines, in the warehouse, and at all electrical substations, the hoistroom, underground crusher room, and several places in the mill. In addition, fire hoses and lines are stratigically located about the mill and surface plant.

TABLE 10. - Distribution of total labor, power, and supply costs charged to mining - 1955

Item	Percent of total labor cost	Percent of total power and supply cost
Operation		
Diamond drilling	1.87	0.67
Drilling and blasting	26.37	38.99
Loading	2.80	.46
Truck and tractor operations	8.05	.51
Crushing and skip loading	3.15	.28
Hoisting	3.46	.18
General underground	5.60	7.20
Power - loading, crushing, hoisting and ventilation		9.23
Power - pumping		1.37
Power and light, general	.98	2.61
Pumping	.03	.01
Vacation and holiday	10.04	
Total - operation	62.35	61.51
Maintenance		
Power shovels and loaders	3.62	5.29
Trucks and tractors	5.35	15.96
Jumbos, drills, etc.	1.68	4.03
Pumps and pump station	.11	.07
Feeder and crusher	.19	2.67
Shaft and headframe	.65	1.28
Other buildings and equipment	2.83	4.34
Total - maintenance	14.43	33.64

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TABLE 10. - Distribution of total labor, power, and supply costs charged to mining - 1955 (Con.)

Item	Percent of total labor cost	Percent of total power and supply cost
Supervision and Services		
Mine supervision	8.72	
Mine office and warehouse	4.57	3.15
Engineering and safety	1.66	
Sampling and analyses	4.30	
Watchmen	2.55	
Geological	1.42	.88
Power		.82
Total - supervision and services	23.22	4.85
Total - labor, power, and supplies	100.00	100.00

TABLE 11. - Distribution of costs of power and supplies used underground - 1955

Item	Percent of total cost of power and supplies
Power	12.23
Explosives	24.48
Fuel oil, lubricating oil, tires, and tubes	7.44
Truck parts	8.31
Tractor and grader parts	6.61
Power shovel parts	.92
Wire rope	.71
Jumbo and drill parts, drill steel, and bits	19.55
Electrical supplies	1.82
Electrical equipment parts	.31
Structural iron and steel	5.65
Lumber	.76
Small tools	.15
Pipe fittings and other hardware	1.77
Mine machinery parts	.93
Miscellaneous supplies	8.36
	100.00

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TABLE 12. - Summary of costs, in units of labor, power, and supplies

Mining

Period covered: Year 1955
Mining method: Open stopes with pillar support
Tons of ore mined: 345,424 long tons

A. Labor	Percent of total	Man-hour per ton
Breaking (drilling and blasting)	22.48	0.098
Loading and grading	7.24	.032
Haulage, crushing, hoisting	18.46	.080
Maintenance	19.61	.086
Supervision and offices	16.37	.072
General	15.84	.069
Total labor	100.00	.437
Average tons per man-shift (underground)		26.45
Average tons per man-shift (surface)		59.26
Average tons per man-shift (total)		18.30
Labor, percent of total cost		63.62
B. Power and Supplies		
Explosives (55 percent semigelatin) (pounds per ton)		0.85
Total power (kilowatt-hours per ton)		5.725
(1) Air compression	1.960	
(2) Loading	.315	
(3) Hoisting	1.177	
(4) Pumping	.353	
(5) Ventilation	1.138	
(6) Crushing	.588	
(7) Lighting	.117	
(8) Drill-jumbo operation	.077	
Other supplies, percent of total power and supplies		63.29
Power and supplies, percent of total cost		36.38

TABLE 13. - Distribution of total labor, power, and supply costs charged to milling - 1955

Item	Labor, percent of total cost	Power and supplies, percent of total cost	Percent of total cost
Operation	29.40	25.94	55.34
Maintenance	11.65	23.99	35.64
Supervision	9.02	-	9.02
Total	50.07	49.93	100.00

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TABLE 14. - Distribution of mill maintenance costs - 1955

Item	Percent of labor cost	Percent of power and supply cost
Crude ore pocket	0.27	1.20
Coarse crushing, screening, conveying	7.84	13.91
Fine crushing, screening, conveying	25.76	34.79
Jigging, dewatering, mill pumps	20.45	10.21
Electrical equipment	18.14	2.33
Fine grinding	1.91	14.74
Water supply, tailing line	4.58	4.25
Tabling	2.12	.12
Heating and ventilating equipment	2.37	1.56
Structures	3.76	9.61
Miscellaneous equipment	10.26	5.15
Experimental	2.54	2.13
Total maintenance	100.00	100.00

TABLE 15. - Summary of costs in units of labor, power, and supplies

Milling

Period covered: Year 1955
Milling method: Gravity concentration
Tons milled: 345,424

	Percent of total	Man-hour per ton
A. Labor		
Operating	70.67	0.106
Maintenance and repair	17.33	.026
Supervision	12.00	.018
Total labor	100.00	.150
Average tons per man-shift		53.24
Labor, percent of total cost		50.07
B. Power and Supplies		
Total power (kilowatt-hours per ton)		7.47
(1) Coarse crushing and screening	1.79	
(2) Fine crushing and screening	1.36	
(3) Jigging	.60	
(4) Fine grinding	2.05	
(5) Water supply	.96	
(6) Tabling	.50	
(7) Lighting	.21	
Power and supplies, percent of total cost		49.93

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